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BREEDING TOBACCO FOR RESISTANCE TO THIELAVIA ROOT ROT

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In Cooperation with the Wisconsin Agricultural Experiment Station

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INTRODUCTION

The black root-rot disease of tobacco caused by *Thielavia basicola* (B. and Br.) Zopf is a common and important disease of tobacco in the United States and in many foreign countries. A remarkable difference in the varietal susceptibility of tobacco to this disease has been shown to exist, and the value of resistant strains in the commercial culture of tobacco has been recognized for some time. Several distinct types of tobacco, however, are grown commercially, and consequently resistant strains of the respective types must necessarily be developed before the standard strains can be replaced. An increasing demand for such resistant strains is anticipated, especially on account of the rapidly growing evidence that the rotation of tobacco with other crops, hitherto regarded as a desirable control measure for black root rot, frequently introduces other factors injurious to the production of the crop.

Some degree of resistance to root rot has apparently been empirically developed within certain types through mass selection of seed by the growers themselves. Some progress has also been made by the selection of chance individuals for resistance and by submitting these to progeny-row trials, but progress by this method is also limited. More rapid and satisfactory progress undoubtedly may be made in most instances by crossing strains most likely to yield the desired results as to resistance, yield, and quality. It is of primary importance in such a procedure that the characteristics and degree of resistance of the existing varieties and strains of tobacco and their value for breeding purposes be known. A knowledge of the genetic behavior of the characters of disease resistance in crosses is equally important to the best progress in the development of resistant commercial types.

This bulletin reports an attempt along these lines of tobacco breeding. The relative resistance of a considerable number of commercial varieties has been determined. Some new resistant commercial strains of tobacco which are desirable have been developed, but progress in the more strictly genetical aspects has been more uncertain and incomplete. The general conclusions as to the genetic behavior of disease resistance in tobacco to Thielavia root rot have been set forth elsewhere.[1]

THE THIELAVIA ROOT-ROT DISEASE

The root-rot disease of tobacco is caused by the ascomycetous fungus *Thielavia basicola*. The lesions of this disease are practically confined to the roots, except on young seedlings, where the base of the stalk may be affected. The roots are reduced in number and the function of the remaining ones more or less interfered with, according to the severity of the attack. The result is a starvation of the aerial part of the plant due to reduced food and water supply. The plants are not killed as a direct result of the disease, since a surprisingly small proportion of the normal root system is sufficient to enable the plants to survive, although they may make no appreciable growth during a period of several months in cases of severe attack. On the other hand, growth may be only temporarily interfered with, and no economic injury may result in cases of light attack. Stages intermediate to these extremes are, of course, of more common occurrence. All other conditions being equal, therefore, the relative weight or height of the plants is a good index of the relative amount of disease in a soil infested with black root rot. (Fig. 1.)

In connection with studies on resistance to the Thielavia root-rot disease it becomes of special importance to recognize the influence of environmental conditions on the results secured. In a previous paper[2] it has been shown experimentally that soil temperature is the most important environmental factor affecting the amount of injury resulting from black root rot. Low soil temperatures (18°–22° C.) favor the disease, whereas high soil temperatures (26° and above) greatly reduce or prevent injury. Furthermore, badly diseased plants are able to make a decided recovery as a result of rising soil temperatures. That variations in soil temperatures comparable to the above occur in the field was shown by soil-temperature readings. The average soil temperature for June, July, and August for the year 1915, for instance, was found to be 20.3° C., whereas for the corresponding period in 1916 the average was 27.7°. These

[1] JOHNSON, J. INHERITANCE OF DISEASE RESISTANCE TO THIELAVIA BASICOLA. (Abstract.) Phytopathology 11: 49. 1921.

[2] JOHNSON, J., and HARTMAN, R. E. INFLUENCE OF SOIL ENVIRONMENT ON THE ROOT-ROT OF TOBACCO. Jour. Agr. Research 17: 41–86, illus. 1919.

conditions were clearly reflected in the amount of disease occurring in the field, i. e., heavy infection in 1915 and light infection in 1916.

VARIETAL RESISTANCE

Earlier work, of a preliminary nature, on varietal resistance in tobacco to Thielavia root rot was reported in 1916.[3] Similar trials for the standard American varieties of tobacco were continued for several years thereafter, together with trials for a considerable number of subvarieties or strains. In addition, several foreign varieties

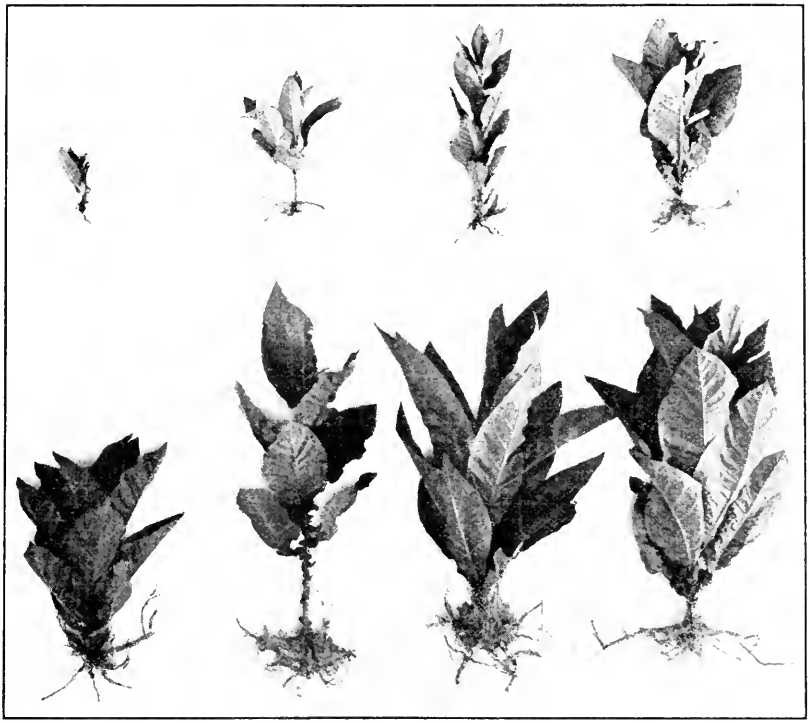

FIGURE 1.—Representative plants of eight varieties of tobacco grown in Thielavia-infested soil, with roots carefully removed from the soil for the purpose of illustrating the correlation between the amount of root rot and the weight and height of the plants

have now been studied sufficiently to be placed in their relative positions for disease resistance. Many of these varieties, furthermore, have been grown in widely different locations, namely, Kentucky, Connecticut, Wisconsin, and Ontario, Canada. In no case has there been any evidence that the inherent resistance of these varieties has been broken down or changed in any way. Furthermore, where soil conditions were uniform the growth of the plants in the trials has been remarkably uniform in the commercial strains tested. The apparent relative changes in behavior which occur in strains from

[3] JOHNSON, J. RESISTANCE IN TOBACCO TO THE ROOT-ROT DISEASE. Phytopathology 6: 167–181, illus. 1916.

year to year may be attributed largely to the influence of environmental factors.

As previously stated, the most important of these environmental factors is the soil temperature. Soil-temperature records over a long period of years are not available, but it is known that these are closely correlated with air temperatures. In Table 1 is shown the distribution of the mean air temperatures at Madison, Wis., for the months of June, July, and August, during a period of years as supplied by the Weather Bureau records. In general, it has been found that the relative resistance of a variety is fairly closely correlated with the mean temperature.

Table 1.—*Distribution of mean air temperatures at Madison, Wis., for years shown*

[From records of U. S. Weather Bureau]

Month	Temperature (° F.) and years																
	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	78	80
								1922									
								1920									
				1912	1918			1913									
				1908	1905			1910									
			1927	1907	1904	1914	1925	1899	1901	1923							
June	1928		1924	1906	1897	1909	1900	1898	1893	1919							
	1917	1926	1903	1892	1885	1891	1888	1896	1887	1911							
	1916	1902	1875	1883	1882	1881	1884	1886	1880	1895							
	1915	1889	1860	1863	1878	1879	1876	1871	1859	1894	1921						
	1869	1874	1854	1858	1877	1872	1861	1862	1853	1890	1870	1873	1857				
										1926	1928						
										1925	1917						
										1913	1899	1911		1919			
									1927	1912	1896	1898		1897			
									1922	1908	1895	1893	1923	1894			
July								1920	1918	1907	1892	1888	1914	1881			
							1924	1905	1909	1903	1890	1885	1910	1879			
							1915	1904	1906	1902	1880	1877	1886	1878			
							1882	1884	1900	1889	1873	1875	1876	1874	1887	1921	
						1891	1853	1869	1883	1871	1858	1872	1870	1857	1859	1916	1901
									1928	1926							
									1921	1925							
						1917			1914	1922							
						1912			1892	1913							
						1907	1924	1920	1889	1910	1906						
August						1904	1923	1919	1875	1905	1901						
						1902	1898	1911	1872	1896	1899	1918					
						1897	1891	1908	1871	1882	1894	1916					
					1927	1884	1888	1893	1858	1880	1886	1909					
					1903	1870	1877	1887	1857	1879	1878	1895		1900			
			1915	1885	1890	1869	1861	1883	1853	1874	1873	1876		1881			

Certain other factors, however, tend to upset the uniformity of results from season to season. Late-maturing varieties, for instance, have a better opportunity to recover from the disease and from other unfavorable conditions than the early maturing varieties. (Fig. 2.) Time of planting, seasonal distribution of rainfall, and other soil conditions influence the experimental results in some degree. These influences are best eliminated as far as breeding trials are concerned by repeating the trials over a period of years.

The procedure in the varietal tests has been fairly simple. The seed used has in all cases come from individual self-fertilized plants except when grown for the first time without the previous history being known. In all cases the seedlings have been grown in sterilized soil so as to prevent any root-rot infection in the seed beds, in addition to insuring strong, uniform plants for transplanting. For all ordinary or preliminary trials about 50 plants of each variety or strain were transplanted in the field and the final green weights of 25 consecutive plants from such rows determined. Usually these plantings were duplicated in the same or in other infested fields for comparison during the same season. Even more important, however, is the duplication of the planting on uninfested soil, which has usually been on fertile plots not previously grown to tobacco. Different varieties of tobacco vary greatly in their habit of growth and in the yield produced, so that it has been necessary always to take into consideration the normal plant for each strain grown under similar seasonal conditions although under different soil conditions.

The relative resistance of the various types in any one experiment is computed on the basis of their yields on infested and uninfested

FIGURE 2.—An early maturing susceptible tobacco variety (Chilean) topping out in center row, compared with a late-maturing susceptible variety (White Burley), at right. The development of the Chilean variety is already limited, but the Burley variety still has some possibility of further growth

soil, i. e., relative resistance is the percentage of normal yield. Estimates of relative growth were also made at frequent intervals throughout the season, and although these data are too voluminous to present they serve to show the relative behavior of the types during the growing period. This may be far from constant, thus accounting in large measure for the change in the relative position of resistance in certain varieties as determined by final weights.

The results of seven years' trials with the common American varieties are shown in Table 2. If the relative resistance for each year is noted it will be seen that a very considerable range exists, the minimum being 3.8 per cent for Maryland Broadleaf in 1915, and the maximum being reached by the Little Dutch variety in 1921 with 84.3 per cent. The table, however, shows that while the relative resistance of the Maryland Broadleaf was 3.8 per cent in the cool season of 1915 it reached the high figure of 51.6 per cent in the warm season of 1921. The Little Dutch, on the other hand, with a maximum of 84.3 per cent in 1921, reached the high minimum of 50.3 per cent in 1915. Manifestly we can not compare the relative resistance shown in one season with that shown in another without taking soil environmental conditions into consideration. The figures for any one year are, however, to be regarded as quite significant in indicating relative resistance, at least for that year and for other years having similar seasonal conditions. From both the genetic and economic standpoints, the relative resistance secured in a normal year is to be regarded as being most significant, and the relative resistance in the years 1917 or 1918 is more likely to represent the normal genetic behavior of the various types, as regards resistance, than is that in the years 1915 or 1916.

TABLE 2.—*Relative resistance of some of the principal varieties of tobacco to Thielavia root rot during different seasons*

Variety	Relative resistance during—							
	1915	1916	1917	1918	1919	1920	1921	Average
White Burley	4.5	19.7	4.7	11.3	10.7	11.1	32.2	13.4
Maryland Broadleaf	3.8	8.2	12.0	16.9	27.2	19.8	51.6	19.9
Pryor	4.2	13.0	24.3	27.2	44.0	26.3	55.2	27.7
Orinoco	5.2	16.7	19.2	26.6	50.8	34.8	58.6	30.2
Connecticut Havana	46.1	52.6	32.6	42.9	52.0	28.2	65.5	45.7
Pennsylvania Broadleaf	16.9	44.0	36.4	58.4	48.8	50.2	72.1	46.7
Connecticut Broadleaf	------	40.0	32.8	60.5	43.5	49.9	64.2	48.5
Little Dutch	50.3	70.6	55.3	58.9	58.9	53.9	84.3	61.7
Shade-Grown Cuban	------	------	51.6	77.4	63.3	44.5	79.7	63.3

In the years 1917 and 1918 the White Burley was the most susceptible variety, followed by varieties showing increasing resistance in approximately the following order: Maryland Broadleaf, Orinoco, Pryor, Connecticut Havana, Connecticut Broadleaf, Pennsylvania Broadleaf, Little Dutch, Shade-Grown Cuban. If the relative resistance over the entire period of the tests is averaged a fairly relative position of the varieties is obtained. (Table 2.) It should be noted in this connection that although standard strains of the various basic types have been used in these tests it is not unlikely that in the case of a few of them other commercial strains of the same type may be more or less resistant than the ones used. This matter would have to be tested by growing a large collection of the various strains from each tobacco district. This has been done in connection with these experiments with only certain of the varieties, especially the White Burley, Havana Seed, and Pryor groups. In these varieties no striking strain differences in the ordinary commercial varieties morphologically true to type have been found. For purposes of ordinary comparison, the basic strains and their subvarieties can be roughly divided into five classes, namely: (1) Very resistant, (2) resistant, (3) intermediate, (4) susceptible, and (5) very susceptible. Such a classification is illustrated in Table 3 for some of the main varieties and subvarieties tested, together with other miscellaneous varieties. This list could be considerably lengthened, but would not be significant without an explanation of the commercial or genetical relationships of the strains.

TABLE 3.—*Varieties and strains of tobacco classified according to resistance to root rot*

Very resistant	Resistant	Intermediate	Susceptible	Very susceptible
Shade-Grown Cuban.	Connecticut Broadleaf.	Havana Seed.	Maryland Broadleaf.	White Burley (14 strains).
Little Dutch.	Resistant White Burley.	Comstock Spanish.	Orinoco (6 strains).	Chilean.
Halladay Havana.	Wisconsin No. 1801.	Zimmer Spanish.	Pryor (12 strains).	
Havana No. 142.	Porto Rican.	Connecticut Havana No. 38.	Big Cuban.	
Brasile Beneventano (Italy).	Yara Cuban.	Pennsylvania Broadleaf.	Maryland Mammoth.	
Xanthia (Turkey).[1]	Wisconsin No. 2901.	Stewart Cuban.	Sumatra.	
	Northern Hybrid.	Brazilian.	Mexican (3 strains).	
		Bagdad (Turkey).		

[1] Practically immune.

GENETIC BEHAVIOR OF RESISTANT CHARACTER

The studies on crosses between resistant and susceptible types of tobacco have been carried on for the most part simultaneously with the varietal studies and in the same fields. The work was done chiefly in the years 1917 to 1920, inclusive, and the seasons of extreme temperature—1915, 1916, and 1921—therefore have been avoided. That the soil used was thoroughly infested with Thielavia root rot and at the same time was in other respects in a good state of fertility is evident from the results obtained from the variety studies.

The crosses were made in the usual manner, and since the varieties crossed differ markedly in various morphological characteristics no difficulty has been experienced in readily distinguishing them. That the parents used were pure strains with respect to the resistant character was evident from their uniformity of growth on infested soil in repeated trials.

When the seedlings (grown on sterilized soil) attained the proper size in the seed beds they were transplanted to progeny rows in the field, strains on which comparative results were most important being placed in close proximity. On account of the number of selections grown each season, it has not been possible to grow many of them in great numbers. Usually only 50 to 60 plants from each selection were employed in the trials, except in the F_2 generations, in which 200 or more were usually planted. In many cases, however, the plantings on infested soil were duplicated, together with controls on uninfested soil.

It is evident that in a disease such as Thielavia root rot no practical method of determining the actual amount of infection on the roots is available, and that even if there were, by its application the usefulness of the plant for further study and seed production would be lost. It has been repeatedly noted that the growth of the plant is an excellent criterion of the development of disease, and in the variety tests the green weight has been used as a basis of calculation.

In the inheritance studies with crosses it has not been advisable to sacrifice potentially important seed plants by harvesting, and consequently plant height has been used as a basis of measurement for resistance. While this method has obvious limitations in cases where the differences are not marked, it has been found applicable in cases where the extremes of the parents differ by as much as 2 or 3 feet in height on infested soil. Measurements were made at about the time when the majority of the plants to be compared were well headed out. Many of the selections, of course, never headed out, and in this case the height from the soil line to the bud was recorded. In the case of plants in the flowering stage the height to the "crow's-foot," i. e., the base of the main inflorescence, was taken. The plants in all cases were measured to the nearest inch and were then placed in 5-inch classes in the frequency-distribution tables.

For convenience the plants were numbered by a system illustrated as follows: White Burley, 6; Little Dutch, 3; the F_1 generation then being 6×3 or 3×6, the female parent being given first. The F_2 generations were designated as 631, 632, etc., for the separate crosses

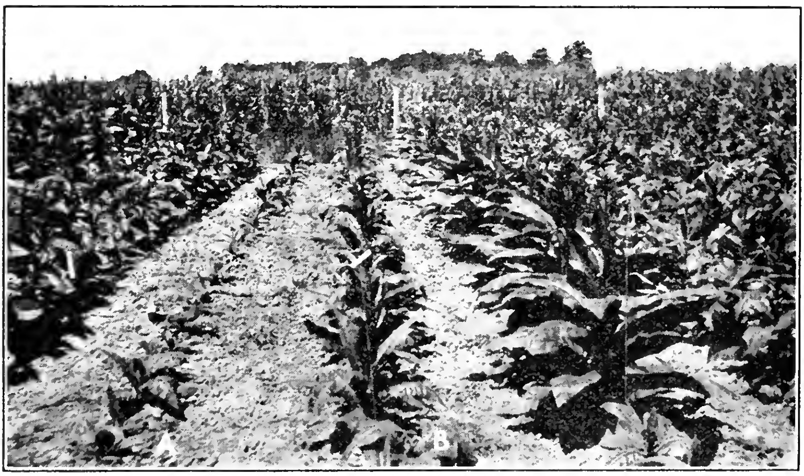

FIGURE 3.—Growth of susceptible White Burley parent (A), resistant Little Dutch parent (C), and the F_1 generation of the cross between the two (B) on Thielavia-infested soil. Compare with Figure 1

made. The types selected for growing in the F_3 were denoted by letters of the alphabet following 63, as 63–A, 63–B, etc. The succeeding generations were designated by adding a digit for each generation, i. e., F_4 as 63–A–1, etc.

LITTLE DUTCH AND WHITE BURLEY CROSS

The major portion of the genetic studies on crosses between varieties of tobacco resistant and susceptible to the Thielavia root-rot disease has been concerned with the cross between the Little Dutch (resistant) and White Burley (susceptible). (Fig. 3.) The Little Dutch is a very vigorous-growing, narrow-leaved type with an upright habit of growth, and was at one time grown extensively in Ohio as a filler type. The White Burley strain used in the first crosses was known as Halley's White Burley, a semiupright, vigorous, large type, but, like most Burley types, not growing so rapidly nor maturing so soon as the Little Dutch, though finally yielding as well on an average, and normally reaching a greater height in the absence of disease.

In Table 4 is compiled a portion of the data secured in 1918 for the Little Dutch and White Burley cross. The calculated means for height, the standard deviations, and the coefficients of variability are given on both infested and uninfested soil for the parents, F_1, F_2, and for two F_3 generations.

TABLE 4.—*Height of plants in the White Burley (susceptible) and Little Dutch (resistant) cross on uninfested and Thielavia-infested soil in 1918*

Designation	Generation	Uninfested soil				Infested soil			
		Plants	Mean height	Standard deviation	Coefficient of variability	Plants	Mean height	Standard deviation	Coefficient of variability
		No.	*Inches*			*No.*	*Inches*		
White Burley (6)	P_1	100	[1] 48.6±0.3	5.0±0.2	10.3±0.5	46	3.0±0.0	0	0
Little Dutch (3)	P_1	122	41.9±0.4	6.7±0.3	16.1±0.7	37	34.5±0.5	4.5±0.3	13.0±1.0
6 × 3	F_1	111	45.1±0.7	11.1±0.5	24.7±1.2	50	26.4±0.7	7.6±0.5	28.8±1.8
631	F_2	121	44.8±0.6	10.8±0.5	24.1±1.1	328	19.2±0.4	10.5±0.3	54.7±1.8
63-H	F_3	111	44.0±0.5	8.4±0.4	19.2±0.9	50	26.5±0.6	6.5±0.4	24.5±1.7
63-R	F_3	93	48.7±0.6	8.7±0.4	17.9±0.9	55	4.4±0.3	2.9±0.2	65.9±5.9
63-B	F_3					57	39.2±0.7	7.5±0.5	19.1±1.2

[1] Measured one week later than others in order to secure approximately the same stage of maturity.

In 1918 the planting on uninfested soil was grown under somewhat unfavorable conditions, and the variation is somewhat above normal. The measurements on the White Burley variety were made later that year than those on the other varieties, on account of the fact that White Burley is a somewhat later maturing type. The true condition is represented more accurately by this delayed measurement than by the earlier measurement made in 1919, as shown in Table 5. The terminal inflorescence represents almost one-third of the height of the plant and develops quickly in healthy, vigorous plants when once the flowering stage has been reached. On uninfested soil the White Burley variety normally is considerably taller than the Little Dutch type, with the F_1 intermediate in height, but quite as large a type as the Burley in other respects. In general, however, the difference in growth as expressed by the height of the plants is comparatively small in the parents and in the F_1, F_2, and F_3 generations grown on uninfested soil. (Fig. 4.) Striking morphological segregation occurs in the F_2 and succeeding generations in all these crosses, but this is much less commonly expressed in height of plant than in shape and size of leaf and habit of growth. No serious discrepancies are to be expected, therefore, in using plant height as a measure of resistance on infested soil as a consequence of morphological variation.

TABLE 5.—*Height of plants in the White Burley (susceptible) and Little Dutch (resistant) cross on uninfested and Thielavia-infested soil in 1919*

Designation	Generation	Uninfested soil				Infested soil			
		Plants	Mean height	Standard deviation	Coefficient of variability	Plants	Mean height	Standard deviation	Coefficient of variability
		No.	*Inches*			*No.*	*Inches*		
White Burley (6)	P_1	52	[1] 29.0±0.6	6.3±0.4	21.7±1.5	45	6.5±0.4	3.6±0.2	55.2±4.9
Little Dutch (3)	P_1	71	45.3±0.3	3.2±0.2	7.1±0.4	43	34.1±0.9	8.6±0.6	25.3±1.9
6 × 3	F_1	73	47.4±0.7	8.7±0.5	18.9±1.4	47	15.5±0.6	6.3±0.4	40.6±3.3
631	F_2	284	43.4±0.3	8.6±0.2	19.9±0.6	418	25.4±0.4	10.9±0.2	42.9±1.2
63–J	F_3	74	44.2±0.7	9.2±0.5	20.9±1.2	53	27.2±0.8	8.6±0.6	31.6±2.3
63–O	F_3	68	46.8±0.6	7.5±0.4	16.0±0.9	50	14.1±0.6	6.7±0.4	47.5±3.9

[1] Slow growing, not topped out. Mean 63.4 inches two weeks later.

By comparing the growth of these strains on infested soil as given in Table 4 it may be seen that the White Burley parent did not extend beyond the 3-inch class, as compared with 34.5 inches for the Little Dutch parent, a difference in height of over 2½ feet. The F_1 is intermediate in height, as is the F_2, but the latter shows a considerably higher coefficient of variability. One F_3 selection (63–R) is almost as susceptible as the susceptible White Burley parent, whereas on uninfested soil it is a vigorously growing type. Another F_3 selection (63–B) is, on the other hand, more resistant than the most resistant parent. The standard deviations are limited in their significance in a comparison of the variations on uninfested soil with those on infested soil. On uninfested soil the normal fluctuating variation of large, rapidly growing, healthy plants is obtained in the parent types, together with that which may be due to heterozygosis for height in the crosses.

FIGURE 4.—The growth of the susceptible White Burley (A), the resistant Little Dutch (B), and the F_1 generation of the cross between these on soil free from disease (C). Compare with Figure 3

In the infested soil the additional variation due to disease is introduced, but with the greatly reduced vigor of growth (from a height of 44.8 to 19.2 inches in the F_2) it is to be expected that the variation due strictly to ordinary heterozygosity for height is correspondingly reduced, whereas that due to differences in resistance is predominant. (Fig. 5.) This can best be illustrated by the standard deviation for 63–R, which is 8.7 ± 0.4 on uninfested soil but only 2.9 ± 0.2 on infested soil. Manifestly the inherent normal heterozygosity for height is as great on the infested as on the uninfested soil, but as a result of the susceptibility to root rot of the variety all other variation is overshadowed. Theoretically, the coefficient of variability of these types on infested and uninfested soil more accurately represents the true state of affairs, because it takes into consideration the relative mean heights. With very susceptible types, however, the coefficient of variability apparently gives too much weight to the relative variability actually occurring, and

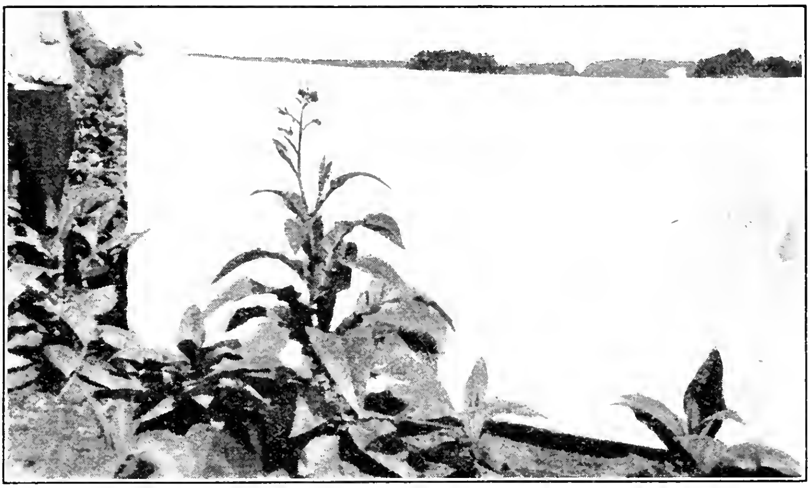

FIGURE 5.—A portion of a row of the F_2 generation of the White Burley and Little Dutch cross, illustrating the degree of segregation for disease

conclusions can be drawn from these statistical methods only in so far as they do not interfere with the actual biological principles involved.

Results of a nature similar to those shown in Table 4 are presented in Table 5 for the 1919 season. The measurements for the White Burley parent on uninfested soil are again not strictly comparable on account of the delayed flowering of this variety.

The mean heights of some F_3 and succeeding generations in comparison with the parental strains are shown in Tables 6 and 7. It may be noted that certain of these strains, F_3 to F_6, are continuing to vary and may be modified in resistance by continued selection, as, for instance, strains 63–C and 63–D. Strains more resistant than the resistant parent and fairly uniform in this characteristic, as, for example, strain 63–K–1, may be secured as early as the F_3 or F_4 generation. (Fig. 6.) On the other hand, strains as susceptible as the most susceptible parent may be isolated, as is illustrated by strain 63–D. That such strains breed approximately true to type is indicated by the behavior of the F_4 and F_5 generations of this strain.

FIGURE 6.—Growth of F_3 and F_4 generation strains of the White Burley and Little Dutch cross on root-rot infested soil. Note the early tendency toward uniformity in the strains

TABLE 6.—*Height of plants in the White Burley (susceptible) and the Little Dutch (resistant) cross grown on Thielavia-infested soil in 1920*

Designation	Generation	Plants	Mean height	Standard deviation	Designation	Generation	Plants	Mean height	Standard deviation
		No.	*Inches*				*No.*	*Inches*	
White Burley (6)	P_1	35	4.7±0.3	2.6±0.2	63–C	F_3	44	20.9±1.1	11.2±0.8
Little Dutch (3)	P_1	29	38.5±0.3	2.4±0.2	63–C–2	F_4	44	19.2±1.0	10.4±0.7
6 × 3 (a)	F_1	27	30.6±0.9	7.4±0.7	63–C–22	F_5	46	11.9±0.7	7.6±0.5
6 × 3 (b)	F_1	52	31.3±0.6	6.7±0.1	63–D–1	F_4	44	40.4±0.7	6.7±0.5
631	F_2	516	31.0±0.3	9.7±0.2	63–K–1	F_4	49	40.1±0.3	3.5±0.2
633	F_2	150	29.0±0.6	10.7±0.4					

TABLE 7.—*Height of plants in the Little Dutch (resistant) and White Burley (susceptible) cross grown on Thielavia-infested soil in 1920*

Designation	Generation	Plants	Mean height	Designation	Generation	Plants	Mean height
		Number	*Inches*			*Number*	*Inches*
Little Dutch (3)	P	53	30.3	63–C–251	F_6	50	21.1
White Burley (6)	P	51	3.1	63–D	F_3	47	14.5
6 × 3	F_1	59	21.4	63–D–1	F_4	45	24.0
63	F_2	266	16.1	63–D–12	F_5	48	33.8
63–R	F_3	55	5.0	63–D–122	F_6	51	41.2
63–R–1	F_4	19	9.5	63–O	F_3	52	4.7
63–G	F	53	35.4	63–O–1	F_4	26	4.1
63–C–1	F_4	50	21.1	63–O–15	F_5	52	6.2
63–C–2	F_4	58	14.4	63–P	F_3	53	17.8
63–C–25	F_5	54	14.6				

It appears from these and other data obtained, as well as from observational evidence, that some resistant individuals breeding true can be obtained from the F_2, but that the majority of selections from this generation are variable in this respect. Selected susceptible individuals from F_2 or succeeding generations yield only susceptible strains, as far as observations have gone in this cross. The evidence, therefore, seems to indicate that resistance is the dominant factor and susceptibility the recessive factor in relation to Thielavia root rot. No evidence of segregation in any simple Mendelian ratio was evident in this case.

The White Burley variety of tobacco used in this cross differs very strikingly from other varieties of tobacco in that the plant is normally much lighter in color, often becoming yellow or "white" as

FIGURE 7.—Fourth-generation families of the White Burley and Little Dutch cross. Note the combination of the resistant character of the Little Dutch with the "white" character of the Burley in the rows to the right. Susceptible strains in the foreground

it nears maturity, as compared with the ordinary varieties of tobacco. This low-chlorophyll-content type is completely obscured by the dominant normal green condition in the F_1. In the F_2 the ratio of "white" to "green" is approximately 1 to 25. The whites always reproduce whites, and the white character is, therefore, the recessive condition. This interesting inheritance of plant color in tobacco has not been studied in detail in the present connection. Resistant White Burley types are readily secured in the F_2 generation, and, while those selected in this case possessed no commercial value, the results suggest the origin of resistant White Burley strains in the field [4] and demonstrate the possibilities of combining resistance with other commercial characters of tobacco. (Fig. 7.)

[4] JOHNSON, J. Op. cit. (See footnote 3.)

OTHER CROSSES OF RESISTANT AND SUSCEPTIBLE VARIETIES

The data presented for the Little Dutch and White Burley cross are supported by the results obtained from several other crosses between resistant and susceptible types. Some of the results of a cross between Connecticut Broadleaf (semiresistant) and White Burley (susceptible) are shown in Table 8. The mean height for the Connecticut Broadleaf variety on infested soil is 37.1 inches, as compared with only 3.6 inches for the White Burley variety.

The F_1 generation, with a mean of 14.5 inches, more nearly approaches the intermediate condition than the mean of either parent. The range of variation in the F_2 generation extends almost to the extremes of the two parents. This F_2 generation is, on the whole, more susceptible than the F_2 generations of the Little Dutch cross with White Burley, indicating that the Connecticut Broadleaf variety, as is to be expected, is not able to transmit as high a degree of resistance in hybridization as the Little Dutch variety.

TABLE 8.—*Height of plants in the Connecticut Broadleaf (resistant) and White Burley (susceptible) cross grown on Thielavia-infested soil in 1918*

Designation	Generation	Plants	Mean height	Designation	Generation	Plants	Mean height
		Number	*Inches*			*Number*	*Inches*
Connecticut Broadleaf (4)	P_1	52	37.1	64-C-2	F_4	57	9.3
White Burley (6)	P_1	53	3.6	64-C-23	F_5	47	7.7
6 × 4	F_1	55	14.5	64-K	F_3	55	16.7
641	F_2	248	14.1	64-L	F_3	50	8.1
64-B-11	F_5	49	26.4	64-N	F_3	48	16.3
64-C	F_3	57	9.0	64-R	F_3	41	30.9

The most resistant plants of the F_2 generation were selfed and grown in the F_3, but none of those selected reached the degree of resistance of the resistant parent 64-R, the nearest approach being made with a mean height of 30.9 inches. Strain 64-C possessed the White Burley character of chlorophyll color and was quite susceptible. Further selection for resistance in the F_3 and F_4 generations failed to increase the relative resistance.

The remainder of the crosses made between resistant and susceptible types were made largely with the purpose of developing resistant commercial varieties of tobacco. This naturally involved considerably more attention to the other desirable characteristics of tobacco in the respective types and less attention to the behavior of inheritance. A general similarity, however, to the results previously described was observed in the following crosses:

Resistant White Burley × White Burley (susceptible).
Resistant Wisconsin strain 2901 × Connecticut Havana No. 38 (intermediate).
Resistant Wisconsin strain 1207 × Connecticut Havana No. 38 (intermediate).
Resistant Wisconsin strain 1207 × Yellow Pryor (susceptible).
Resistant Shade Cuban × Big Cuban (susceptible).
Resistant White Burley × Orinoco (susceptible).

The statistical data secured upon the inheritance in these crosses are too limited to be profitably presented. The first two crosses named have yielded commercial varieties, however, which are briefly described in the following pages. (Fig. 8.)

RESISTANT STAND-UP WHITE BURLEY

The selection of resistant White Burley strains for commercial purposes has been discussed in an earlier paper.[5] About the time that the earlier resistant strain of White Burley was introduced, "stand-up" or erect-leaved strains of Burley were replacing the original drooping or pendent-leaf strains, to which the original resistant Burley belonged. It was consequently desirable to develop a resistant strain of stand-up White Burley. Field selections from standard stand-up strains offered no hope of a resistant strain. A strain of drooping-leaved resistant White Burley was, therefore, crossed with a strain of susceptible stand-up White Burley (Judy's Pride), and selections were made in the F_2 and succeeding generations for a resistant stand-up White Burley. (Figs. 8 and 9.) Several apparently desirable strains were secured, and the best one of these, all factors being considered, was finally

FIGURE 8.—A drooping-leaved resistant White Burley strain (A), a stand-up susceptible White Burley strain (C), and the F_1 generation of the cross between these (B)

distributed for trial to Burley growers in Kentucky, Ohio, and Canada. This strain may be grown for several years on the same land as far as Thielavia is concerned, whereas ordinary Burley, owing to its susceptibility, would prove a complete failure. Objection to the thinness of the leaf in this strain has been offered in some instances, but excellent crops as to both yield and quality have been reported in others. This strain is now commonly grown in the Burley district of Canada.

The development of additional new strains of root-rot resistant White Burley of commercial value may be expected to come in the future from various sources. It is to be expected, however, that these may vary considerably in the actual degree of resistance exhibited (fig. 10) as well as in relative yield and quality. It will then remain to determine by careful comparative trials, made under

[5] JOHNSON, J., and MILTON, R. H. STRAINS OF WHITE BURLEY TOBACCO RESISTANT TO ROOT-ROT. U. S. Dept. Agr. Bul. 765, 11 p., illus. 1919.

different soil and seasonal conditions, the relative commercial merits of such strains.

RESISTANT HAVANA NO. 142

The Havana Seed variety of tobacco, a type commonly grown in Wisconsin, the Connecticut Valley, and to some extent in New York and Pennsylvania, is fairly susceptible to Thielavia root rot.[6] Repeated efforts were made to secure a resistant strain of this variety of tobacco by field selection, but the resistant strains secured were usually undesirable as to habit of growth of the plant or as to quality of leaf produced. One of these strains, No. 1801, became quite generally grown in Wisconsin under the name of "root-rot resistant cigar binder." This strain was, however, only moderately resistant and met with some objections as to quality. Its distribution, therefore, was discontinued, although it was at one time grown fairly extensively in Wisconsin and is still being grown on a small scale.

FIGURE 9.—Progeny row trials of strains of White Burley

As a consequence of the studies on the crosses between susceptible and resistant strains, it became evident that the most rapid progress in the development of a resistant Havana Seed strain could be made by crossing the latter with the most promising of the undesirable resistant strains. A desirable strain of Havana Seed, known as Connecticut Havana No. 38, previously developed in Wisconsin and widely grown in that State, was crossed with two resistant selections, strains 1207 and 2901. The latter, which was a selection from a strain of seed known as Page's Comstock, but which was quite dissimilar to the well-known Comstock Spanish strain of Wisconsin, proved to be the most desirable parent, and selections in the succeed-

[6] JOHNSON, J. Op. cit. (See footnote 3.)

ing generations were continued largely from this cross. Several strains even more resistant than the resistant parent, with greatly improved habit of growth and leaf number, were secured.

FIGURE 10.—A, A resistant stand-up White Burley strain; B, a susceptible stand-up White Burley strain; C, a so-called resistant strain of Burley distributed commercially by certain seed growers

A few years' trial indicated that strain No. 142, everything being considered, was the most desirable. This strain was consequently distributed to a few growers and was favorably received. The culture of the strain spread very rapidly in Wisconsin and has met with considerable approval in the Connecticut Valley. Havana No. 142 is somewhat later in maturing than Havana Seed, but if it is planted sufficiently early on old tobacco land, for which it is intended, maturity will be reached under ordinary circumstances. On Thielavia-infested soil the strain will greatly outyield ordinary Havana Seed. (Fig. 11.) It has a distinct advantage in that it permits repeated culture of tobacco on the same land, and thereby the possible injurious effects of crop rotation on tobacco are avoided.

DISCUSSION OF RESULTS

It has been shown that varieties of tobacco differ greatly in their degree of resistance to the root-rot disease caused by *Thielavia basicola.* This difference is of such magnitude that it was believed at the outset that it might offer a good opportunity for the study of the inheritance of disease resistance. Certain disadvantages however exist, the most important being the necessity for using an indirect measure of the amount of disease present, the influence of

FIGURE 11.—Connecticut Havana No. 38 (A), the parent strain, with an intermediate degree of resistance, growing on Thielavia-infested soil, in comparison with the very resistant Havana No. 142 strain (B), now grown commercially on an extensive scale

time of flowering or maturity on such measurements, and the influence of environmental conditions, especially soil temperature, on the development of the disease. Similar influences are, of course, encountered to a greater or lesser extent in inheritance studies of all quantitative characters. While these interferences are reflected throughout the data, it is believed that the results secured express satisfactorily the behavior of the root-rot resistant character in tobacco.

The crosses between resistant and susceptible types have in all cases shown the first generation to be more or less intermediate in resistance. The prevailing environmental conditions may naturally influence the relative resistance of the F_1 as it does that of the parents. The second generation of crosses between resistant and susceptible varieties breaks up into types of varying degrees of resistance, certain individuals being as resistant as or more resistant than the resistant parent, and others as susceptible as the susceptible parent. Almost the entire population of individuals is, however, between these extremes. New combinations of the resistant character with other plant characters naturally occur, so that it is possible, by selection, to secure plants of the general type of the susceptible parent, having in addition the resistant factor of the other parent. In the third generation certain individual selections will continue to vary in the same manner as the F_2, whereas others apparently breed true for resistance. Susceptibility appears to be the recessive condition.

During the several seasons in which these crosses have been grown no evidence has been obtained that would indicate a segregation according to any simple Mendelian ratio. The hypothesis of multiple factors as propounded by Nilsson-Ehle [7] and others for the inheritance of certain quantitative characters seems to apply in the case of the inheritance of resistance to Thielavia root rot in tobacco. The inheritance of disease resistance in tobacco is, therefore, much like that found in recent years to occur in the case of many other hosts.

While much remains to be done in the way of a more detailed study of the genetic aspects of disease resistance in tobacco, the results secured in this investigation have demonstrated some of the methods and possibilities relative to the development of root-rot resistant commercial strains of tobacco. That such a line of endeavor is worthy of the effort is illustrated by the development of two strains of tobacco, namely, the root-rot resistant Havana No. 142 and the resistant stand-up White Burley, both of which are extensively grown on a commercial scale. The present understanding of the relative resistance of tobacco varieties, some of which, like Xanthia, are practically immune to root rot, together with a rough idea of the mode of inheritance, the relation of environment to the disease, and the nature of this resistance as suggested by the histological studies made by Conant [8] in this laboratory, should form a basis for more complete genetic researches on disease resistance in tobacco.

SUMMARY

The relative resistance to Thielavia root rot of most of the important commercial varieties and strains of tobacco grown in the United States and in many foreign countries has been studied. Many of these varieties have been placed in one of five classes according to their resistance to the disease.

Environmental conditions, especially soil temperature, influence to a decided extent the apparent relative resistance of any variety to the root-rot disease, low temperatures (18°–22° C.) favoring the disease and high temperatures (above 26°) being unfavorable to it.

The time of maturity of a variety also influences the apparent relative resistance. Early maturing susceptible varieties are usually most seriously affected. Late-maturing susceptible varieties are more likely to recover partially from the effects of the disease.

While these facts do not in any way affect the actual genetic resistance or susceptibility of a variety, it is important that they be taken into consideration in drawing conclusions as to the genetic

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[7] NILSSON-EHLE, H. KREUZUNGSUNTERSUCHUNGEN AN HOFER UND WEIZEN. Lunds Univ. Arsskr. (n. F. Afd. 2) 7: 57–82. 1911.

[8] CONANT, G. H. HISTOLOGICAL STUDIES OF RESISTANCE IN TOBACCO TO THIELAVIA BASICOLA. Amer. Jour. Bot. 14: 457–480, illus. 1927.

resistance or susceptibility of varieties or crosses in experimental trials.

The first generation of a cross between root-rot resistant and susceptible types is intermediate in resistance. The second generation yields individuals of all grades of resistance from those even more resistant than the most resistant parent to others as susceptible as the susceptible parent.

In the third generation certain families continue to vary in respect to resistance, while other families apparently breed true for this character. Susceptible F_2 individuals, especially, breed true for susceptibility. Resistance is believed to be the dominant condition and susceptibility the recessive condition.

The inheritance of disease resistance in tobacco does not seem to follow any simple Mendelian ratio, but behaves in a manner that may be more satisfactorily explained by the multiple-factor hypothesis.

The development of two root-rot resistant commercial varieties of tobacco is described, namely, the resistant Havana No. 142 and the resistant stand-up White Burley.

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TECHNICAL BULLETIN No. 174 APRIL, 1930

THE AIR SEASONING OF WOOD

BY

J. S. MATHEWSON

Senior Engineer, Forest Products Laboratory
Branch of Research, Forest Service

UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D. C.

For sale by the Superintendent of Documents, Washington, D. C. - - - - - - - - - - Price 35 cents

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UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

THE AIR SEASONING OF WOOD

By J. S. MATHEWSON[1]

Senior Engineer, Forest Products Laboratory,[2] Branch of Research, Forest Service

CONTENTS

INTRODUCTION

PURPOSE OF THE BULLETIN

The fullest utilization of our forest crop requires that the wood harvested from forests and wood lots be brought to a condition best suited to its ultimate use. One of the essential steps in securing maximum utilization is to season the stock to the proper moisture

[1] The author wishes to acknowledge his indebtedness to other members and former members of the Forest Service, particularly the authors of Department Bulletin No. 1425, The Air Seasoning of Western Softwood Lumber, S. V. Fullaway, jr., formerly in charge of the office of forest products, Missoula, Mont., Herman M. Johnson, assistant in forest products, Portland, Oreg., and C. L. Hill, forester, California Forest Experiment Station. Further, acknowledgement is also made to numerous lumber companies and associations, whose effective cooperation was essential to the conduct of the investigations upon which this bulletin is based.

[2] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

content, at the same time keeping waste and degrade to a minimum. Although the inherent properties of the wood of a tree are determined initially by the species and growth conditions of the tree itself, they can be modified by proper methods of seasoning. It is evident, therefore, that seasoning is one of the important factors in the conservation of our forest resources. Realizing this fact, the Forest Products Laboratory has been studying the entire problem of seasoning for a number of years. The results of the investigations concerned with air seasoning are embodied in this bulletin.

The purpose of this bulletin is threefold: To present the general principles involved in the drying of wood, to show their application to air seasoning, and to offer suggestions for better air-seasoning practice. Better practice will reduce seasoning losses, decrease the drain on our forests, and give to the consumer material that is better suited to his needs.

A large number of studies of seasoning have been made by the Forest Service in various parts of the United States.[3] These studies have shown that the fundamental principles of air seasoning and of kiln drying are the same. Consequently the results derived from kiln-drying investigations often help to solve problems that arise in air seasoning and conversely, although adequate recognition of any important differences in conditions is always necessary. This bulletin assembles the pertinent results of the Forest Service air-seasoning studies; it includes especially the quantitative results of the field studies of air seasoning made in the West on sugar pine, western yellow pine, redwood, western white pine, and Douglas fir.

Complete data pertaining to the volume of wood products air seasoned in the United States are not available; however, more than half of such products are air seasoned for a time, even though some of them may subsequently be kiln dried. Hence the importance of improvement in air-seasoning practice is obvious.

PURPOSE OF SEASONING

Broadly, the principal object in seasoning wood is to improve its suitability for the purpose for which it is to be employed, although in some instances the reduction in transportation costs may be of paramount importance.

AIR SEASONING

Among the results accomplished by employing proper methods of air seasoning of wood are the following:

A reduction in weight, with a resulting reduction in shipping costs.

A reduction in the shrinkage, checking, honeycombing, and warping occurring in service.

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[3] The results of the general studies of kiln drying have been published in U. S. Dept. Agr. Bul. 1136 (*5*) (italic numbers in parentheses refer to Literature Cited, p. 56), and the results of some special kiln-drying studies in Technical Bul. 165, U. S. Dept. Agr. (*4*). Similarly the results of studies of air seasoning made in the principal lumbering regions of the West have been reported in U. S. Dept. Agr. Bul. 1425 (*1*). The national committee on wood utilization of the U. S. Department of Commerce has prepared four reports entitled "Seasoning, Handling, and Care of Lumber," which are designated, respectively, the consumers', the distributors', the fabricators', and the manufacturers' edition (*6, 7, 8, 9*).

A decrease in the tendency for blue stain and for other forms of mold to develop.

A reduction in liability to some forms of insect attack.

An increase in strength.

An improvement in the ability of the stock to be painted or to be impregnated with a preservative.

KILN DRYING[4]

Among the advantages over air seasoning that may result from kiln drying are the following:

A reduction in weight, and consequently in shipping charges, even greater than the reductions common for air-seasoned stock.

A reduction in moisture content to any desired value, which in many instances may be lower than that obtainable through air seasoning.

A reduction in drying time below that required in air seasoning.

The killing of any stain or decay fungi or insects that may be in the wood.

THE SOLUTION OF INDIVIDUAL AIR-SEASONING PROBLEMS

No single general rule is applicable to all seasoning problems; each individual problem requires its own special modifications of the general rules if satisfactory seasoning at minimum cost is to be attained. The following five distinct objectives must be borne constantly in mind in selecting the seasoning procedure to be followed in each instance: (1) Minimum depreciation of stock, (2) rapid rate of drying, (3) low and uniform moisture content, (4) economy in operating cost, and (5) low investment cost. Maximum attainment of any one of these objectives may often preclude full realization of the others.

Other complications of the seasoning problem should also be recognized. The various species of wood and the grades and sizes of stock require individual consideration. Because of climatic and other differences, the solution for one seasoning yard will not always hold for another. Seasonal weather variation must likewise be met individually by each yard.

It has therefore become obvious that the solution of the air-seasoning problem can not be found in any set of fixed rules. Consequently the chief aim of this bulletin is the presentation of rather general principles, based on the detailed knowledge available, which can be applied in a manner that will best meet specific conditions and problems.

To permit an orderly presentation of the information available, the major discussion is preceded by a brief review of the general principles of drying wood and by a statement of their application to the air-seasoning process.

MOISTURE IN WOOD

COMPOSITION OF SAP

The moisture in wood is commonly called "sap," although the use of this multipurposed term is often misleading. Sap in wood is chiefly water, but it also contains small percentages of soluble organic

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[4] The Kiln Drying Handbook (5) presents a full discussion of the general subject of kiln drying and of matters related thereto.

and mineral matter. In the sapwood such materials are largely sugars, while in the heartwood a considerable proportion of them may be tannins and coloring matter. For all practical purposes in the drying of wood, however, sap may be considered as water alone.

OCCURRENCE OF MOISTURE

Moisture (sap) in green or wet wood is held in two ways. It is contained within the cell cavities, and it is absorbed in the cell walls. The bulk liquid is called "free" water, while the absorbed may be termed "imbibed" water.

VARIATION IN AMOUNT OF MOISTURE

Some free water is present in both the heartwood and the sapwood of most living trees, but the amounts in each differ greatly. Sapwood usually contains more moisture than heartwood does. Butt logs ordinarily have a higher moisture content than top logs. Contrary to common opinion, the variation during the year in the amount of moisture in green wood is slight. Species and place of growth, however, have an important bearing upon the amount of moisture in the living tree.

Marked variation in the moisture content of trees was indicated by the many moisture-content determinations on green wood made in connection with air-seasoning investigations in the western part of the United States. Differences among species were large. In all species, the select grades of green lumber contained more moisture than the common grades because of the greater proportion of sapwood in the clearer stock. Variation resulting from place of growth was well illustrated by the moisture-content values of western yellow pine stock in California and of that in the Inland Empire.[5] A usual range of moisture content for this species in the Inland Empire was from 80 per cent in the common grades to 115 per cent in the select grades, while in California the corresponding values were from 100 to 185 per cent. The following species showed moisture-content values, averaging about as indicated, for common and for select grades, respectively: Western white pine, 75 and 84 per cent; sugar pine, 75 and 190 per cent; white fir, 90 and 200 per cent; redwood, 70 and 200 per cent; coast Douglas fir, 32 and 53 per cent; and western hemlock, 28 and 120 per cent.

DETERMINATION OF MOISTURE CONTENT

The amount of moisture in wood, which is termed the moisture content, is ordinarily expressed as a percentage of the weight of oven-dry wood. Thus, if the moisture content of a green board is 71 per cent, there are by weight 71 parts of water to 100 parts of oven-dry wood. Again, should the moisture content of a board be exactly 100 per cent, the weight of the moisture and that of the oven-dry wood are equal; each is then half the total weight of the board. If the moisture content is 150 per cent, for example, the

[5] Northwestern Montana, Idaho north of the Salmon River, Washington east of the Cascade Mountains, and the northeastern tip of Oregon.

moisture is three-fifths and the oven-dry wood is two-fifths of the total weight of the board.

The average moisture content of any lot of lumber may be determined in the following manner:

(1) Select representative pieces, being careful to include typical amounts of both heartwood and sapwood, and taking about 1 out of every 100 pieces in the lot.

(2) Trim from one end of each piece a length of about 2 feet, making the cut at a place free from knots, rot, pitch streaks, and other defects. (The section must be far enough from the end to certainly avoid the effects of end drying; in addition, however, it is desirable to place the first cut so that the second one will leave the remaining piece of lumber sufficient for some standard length.)

(3) From the freshly exposed ends of each piece cut off a section three-fourths to 1 inch long in the direction of the grain.

(4) Trim all slivers off the sections.

(5) Weigh the individual sections immediately and carefully on a delicate balance. Each reading gives the original weight of a section.

(6) Place the sections in an oven heated to 212° F., or, if an oven is not available, on hot steam pipes, but do not scorch them; the maximum variation in the drying temperature should be not more than 5° between limits.

(7) When the sections have reached a constant weight, a condition that can be determined by repeated weighing, remove them from the oven. (After a little experience the time required to reach constant weight can be estimated with sufficient accuracy and some repeated weighings may thus be avoided. Twenty-four hours is about the maximum time necessary.) The final weight of a section is its oven-dry weight.

(8) Subtract each oven-dry weight from the corresponding original weight. Each difference, when the work has been properly done, is the loss in moisture of the section concerned.

(9) Divide the difference just obtained by the oven-dry weight and multiply the result by 100 for each section. Each final result is the percentage of moisture contained in the wood of a section, based on its oven-dry weight.

(10) Find the mean value of these individual percentages in order to obtain the average moisture content of all the sections. The result is considered the average moisture content of the lot of lumber that was sampled.

An example of the calculation for a typical moisture-determination section follows:

Original weight=284.7 grams.
Oven-dry weight=180.2 grams.
284.7 grams−180.2 grams=104.5 grams of moisture lost.
(104.5 grams ÷ 180.2 grams)×100=58 per cent moisture originally in the wood.

For convenience and accuracy the gram is preferably used in moisture determination as the unit of weight, but other units, such as the ounce, may be employed. The scales customary in work on moisture-determination sections, however, are graduated in grams; a fraction of a gram is conveniently expressed as a decimal.

APPARATUS FOR MOISTURE DETERMINATION [c]

BALANCES

For weighing ordinary moisture-determination sections it is advantageous to use balances having a capacity of about 200 grams and sensitive to 0.1 gram. Several types are considered satisfactory: The ordinary analytical balance, the pans of which are suspended from a beam; the Harvard trip scale, which has the pans supported

[c] See footnote 4.

on top of its main beam and is provided with a scale beam and rider of 10 grams capacity; the torsion balance in which the beams are below the pans; and the triple-beam balance, in which the pan is suspended from one end of a multiple beam. Separate brass weights are used with the first three types, although the Harvard trip scale has also a small scale beam and rider. Balance is accomplished with the fourth type by means of a separate rider on each of the three units of the multiple beam.

For weighing larger samples or whole boards a platform scale having a capacity of 100 pounds or more and sensitive to 0.01 pound is quite satisfactory. Such a scale, although usual in type, is somewhat exceptional in quality, and only the better manufacturers make it.

OVENS

Both steam and electric ovens are in common use for drying moisture-determination sections. A suitable steam oven can be made of galvanized sheet iron, well insulated with mineral wool or equivalent material. It should be heated by means of a steam coil placed in the lower part, and ventilated by openings near the top and the bottom. Above the steam coil open shelves, usually of wire lattice or grating, should be provided for the sections. Steam ovens are generally home made. Electric ovens in which the heating element is thermostatically controlled may be purchased from various manufacturers.[7]

The moisture-determination sections, with either type of oven, should be open piled in order to permit good circulation of air around each piece and thus hasten drying. If some sections are dry and a large number of very wet sections are then placed in the oven, the dry sections may absorb moisture. Care should therefore be taken to avoid weighing supposedly dry sections under such a condition. It would be far better to weigh the previously dry sections either before the green sections are placed in the oven or after the green sections have become dry.

MOISTURE AND HUMIDITY

Wood possesses the property of giving off or taking on moisture from the surrounding atmosphere until the moisture in the wood has come to a balance with that in the atmosphere. This action is illustrated by Figure 1 which, for example, shows that wood, kept in an atmosphere constantly at 70° F. and 60 per cent relative humidity, will eventually come to a moisture content of about 11 per cent. The relative humidity of the surrounding air, therefore, is a very important factor in the seasoning of wood, and a general understanding of the relationship between humidity and drying is essential in any consideration of seasoning problems.

Absolute humidity is the weight of the water vapor contained in a unit volume of space; it is usually expressed as the number of grains of moisture per cubic foot (7,000 grains = 1 pound avoirdupois). It does not indicate the drying capacity of the air, however, since the capacity of air to hold water, as illustrated by Table 1, varies greatly with temperature.

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[7] A list of dealers handling apparatus for moisture-content determination will be furnished by the Forest Products Laboratory, Madison, Wis., upon request.

TABLE 1.—*Moisture capacity of air at different temperatures at normal atmospheric pressure*

Temperature	Weight of moisture at saturation
° F.	*Grains per cubic foot*
20	1.2
40	2.9
60	5.8
80	11.1
100	20.0

RELATIVE HUMIDITY

Air containing the total number of grains of water vapor that it can hold at its temperature is saturated. The ability of air to dry

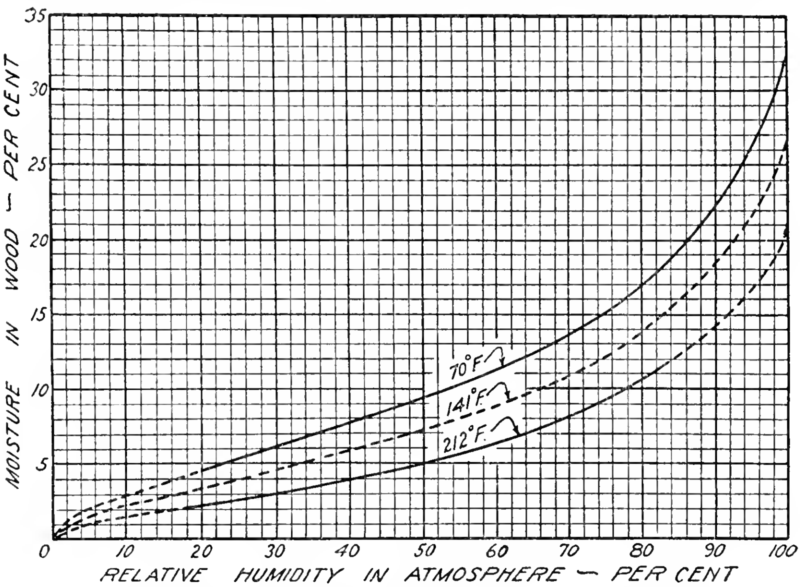

FIGURE 1.—Relation of the equilibrium moisture content of wood to the relative humidity of the surrounding atmosphere, at three temperatures

wood or any other substance varies with the amount of additional moisture it can hold before becoming saturated. The amount of vapor actually in the air, expressed as a percentage of the amount it would hold at saturation, is called its "relative humidity." The relative humidities of two equal amounts of air at the same temperature indicate their comparative drying abilities. Low humidities represent dry air and high ones moist air.

Referring to Table 1, 1.2 grains of moisture will saturate a cubic foot of air at 20° F.; the relative humidity of that air is then 100 per cent. If the air and its moisture are raised to a temperature of 80°, however, its relative humidity will decrease from 100 per cent to 11 per cent, thus:

$$\frac{1.2 \text{ grains}}{11.1 \text{ grains}} \times 100 = 11 \text{ per cent.}$$

At 100 per cent relative humidity air can not dry wood because it can hold no more moisture. At 11 per cent relative humidity, on the other hand, it may dry wood entirely too rapidly because of the great capacity for moisture it then has. At 60° the same air, with a relative humidity of about 21 per cent, perhaps would still dry wood more rapidly than is desirable. During the summer the relative humidities at representative points in the United States usually are between 40 and 80 per cent, although in very dry inland spots they may run as low as 20 per cent and on water fronts, especially on large bodies of water, they may go well above 90 per cent.

Assuming constant temperature and circulation, the drying of a given piece of wood depends entirely upon the humidity of the atmosphere surrounding it. On the other hand, when a given piece of wood is subjected to a given humidity the rate at which it loses moisture depends upon its moisture content; the higher its moisture content the faster it loses moisture.

Changes in atmospheric humidity range from the usual daily fluctuations to marked seasonal variations. Thus wood, when exposed to ordinary atmospheric conditions, is practically always undergoing at least slight changes in moisture content because of its tendency to come to definite balance with the surrounding air. This action accounts for the variation in final moisture content of thoroughly air-dry wood at different times of the year. The pick-up in moisture content of lumber left in a yard over the winter is likewise explained. Figure 1 shows the ultimate moisture content of wood when the wood is kept under constant temperature and relative humidity conditions for a sufficient length of time.

APPARATUS FOR RELATIVE-HUMIDITY DETERMINATION [8]

A very common method of determining relative humidity is by means of a wet-bulb and dry-bulb hygrometer. This instrument consists of two glass thermometers, the bulb of one of which is enveloped in a wick kept moist with distilled water, supplied from a small reservoir attached to the base of the instrument.

If the relative humidity is less than 100 per cent and a brisk air movement past the wick is taking place (it should be at least 15 feet per second), the reading of the wet-bulb thermometer will be less than that of the dry-bulb thermometer as a result of the cooling effect produced by the evaporation of moisture from the wick. The greater the difference between the two readings, the lower is the relative humidity, other conditions remaining constant. Table 2, which is based on experimental data, shows the relationship between dry-bulb temperature, the difference between wet-bulb and dry-bulb temperatures, and relative humidity.

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[8] See footnote 4.

TABLE 2.—*Relative humidity table for use with wet-bulb and dry-bulb thermometers*

Temperature of dry bulb (° F.)	Difference between wet-bulb and dry-bulb thermometers, in degrees Fahrenheit																																																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
60	94	89	83	78	73	68	63	58	53	48	43	39	34	30	26	21	17	13	9	5	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
70	95	90	86	81	77	72	68	64	59	55	51	48	44	40	36	33	29	25	22	19	15	12	9	6	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
80	96	91	87	83	79	75	72	68	64	61	57	54	50	47	44	41	38	35	32	29	26	23	20	18	15	12	10	7	5	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
90	96	92	89	85	81	78	74	71	68	65	61	58	55	52	49	47	44	41	39	36	34	31	29	26	24	22	19	17	15	13	11	9	7	5	3	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
100	96	93	89	86	83	80	77	73	70	68	65	62	59	56	54	51	49	46	44	41	39	37	35	33	30	28	26	24	22	21	19	17	15	13	12	10	8	7	5	4	2	1	-	-	-	-	-	-	-	-
102	96	93	90	86	83	80	77	74	71	68	65	62	60	57	55	52	49	47	45	42	40	38	36	34	32	30	28	26	24	22	20	18	16	15	13	11	10	8	7	5	4	2	1	-	-	-	-	-	-	-
104	97	93	90	87	83	80	77	74	71	69	66	63	60	58	55	53	50	48	46	43	41	39	37	35	33	31	29	27	25	23	21	20	18	16	14	13	11	10	8	7	5	4	2	1	-	-	-	-	-	-
106	97	93	90	87	84	81	78	75	72	69	66	64	61	58	56	53	51	49	46	44	42	40	38	36	34	32	30	28	26	24	23	21	19	17	16	14	13	11	10	8	7	5	4	3	1	-	-	-	-	-
108	97	93	90	87	84	81	78	75	72	70	67	64	62	59	57	54	52	49	47	45	43	41	39	37	35	33	31	29	27	25	24	22	20	19	17	16	14	12	11	10	8	7	5	4	3	2	-	-	-	-
110	97	93	90	87	84	81	78	75	73	70	67	65	62	60	57	55	52	50	48	46	44	42	40	38	36	34	32	30	28	26	25	23	21	20	18	17	15	14	12	11	10	8	7	6	4	3	2	1	-	-
112	97	94	90	87	84	81	79	76	73	70	68	65	63	60	58	55	53	51	49	47	44	42	40	38	36	35	33	31	29	27	26	24	23	21	19	18	16	15	14	12	11	9	8	7	6	4	3	2	1	-
114	97	94	91	88	85	82	79	76	74	71	68	66	63	61	58	56	54	52	49	47	45	43	41	39	37	35	34	32	30	28	27	25	24	22	20	19	18	16	15	13	12	11	9	8	7	6	5	3	2	1
116	97	94	91	88	85	82	79	76	74	71	69	66	64	61	59	57	54	52	50	48	46	44	42	40	38	36	34	33	31	29	28	26	25	23	22	20	19	17	16	14	13	12	11	9	8	7	6	5	4	2
118	97	94	91	88	85	82	79	77	74	72	69	67	64	62	59	57	55	53	51	49	47	45	43	41	39	37	35	34	32	30	29	27	25	24	23	21	20	18	17	16	14	13	12	11	9	8	7	6	5	4
120	97	94	91	88	85	82	80	77	74	72	69	67	65	62	60	58	55	53	51	49	47	45	43	41	40	38	36	34	33	31	29	28	26	25	23	22	21	19	18	17	15	14	13	12	10	9	8	7	6	5
122	97	94	91	88	85	83	80	77	75	72	70	67	65	63	60	58	56	54	52	50	48	46	44	42	40	39	37	35	34	32	30	29	27	26	24	23	22	20	19	18	16	15	14	13	11	10	9	8	7	6
124	97	94	91	88	85	83	80	78	75	73	70	68	65	63	61	59	57	54	52	50	48	47	45	43	41	39	38	36	34	33	31	30	28	27	25	24	22	21	20	18	17	16	15	14	12	11	10	9	8	7
126	97	94	91	88	86	83	80	78	75	73	70	68	66	64	61	59	57	55	53	51	49	47	45	44	42	40	38	37	35	33	32	30	29	27	26	25	23	22	21	19	18	17	16	15	13	12	11	10	9	8
128	97	94	91	89	86	83	81	78	76	73	71	68	66	64	62	60	58	56	54	52	50	48	46	44	42	41	39	37	36	34	33	31	30	28	27	25	24	23	22	20	19	18	17	16	14	13	12	11	10	9
130	97	94	91	89	86	83	81	78	76	73	71	69	67	64	62	60	58	56	54	52	50	48	47	45	43	41	40	38	37	35	33	32	30	29	28	26	25	24	22	21	20	19	18	16	15	14	13	12	11	10
132	97	94	92	89	86	84	81	79	76	74	71	69	67	65	63	61	58	56	55	53	51	49	47	45	44	42	40	39	37	36	34	33	31	30	28	27	26	24	23	22	21	20	18	17	16	15	14	13	12	11
134	97	94	92	89	86	84	81	79	76	74	72	69	67	65	63	61	59	57	55	53	51	49	48	46	44	43	41	39	38	36	35	33	32	30	29	28	26	25	24	23	21	20	19	18	17	16	15	14	13	12
136	97	94	92	89	86	84	81	79	77	74	72	70	68	65	63	61	59	57	55	54	52	50	48	46	45	43	41	40	38	37	35	34	33	31	30	28	27	26	25	23	22	21	20	19	18	17	16	15	14	13
138	97	94	92	89	87	84	82	79	77	75	72	70	68	66	64	62	60	58	56	54	52	50	49	47	45	44	42	40	39	37	36	35	33	32	30	29	28	27	25	24	23	22	21	20	19	17	16	15	14	14
140	97	95	92	89	87	84	82	79	77	75	73	70	68	66	64	62	60	58	56	54	53	51	49	47	46	44	43	41	40	38	37	35	34	32	31	30	29	27	26	25	24	23	21	20	19	18	17	16	15	14
142	97	95	92	89	87	84	82	80	77	75	73	70	68	66	64	62	60	58	57	55	53	51	49	48	46	44	43	42	40	39	37	36	34	33	32	30	29	28	27	26	24	23	22	21	20	19	18	17	16	15
144	97	95	92	89	87	84	82	80	78	75	73	71	69	67	65	63	61	59	57	55	53	52	50	48	47	45	44	42	41	39	38	36	35	34	32	31	30	29	27	26	25	24	23	22	21	20	19	18	17	16
146	97	95	92	90	87	85	82	80	78	75	73	71	69	67	65	63	61	59	57	56	54	52	50	49	47	45	44	43	41	40	38	37	36	35	33	32	30	29	28	27	26	25	24	22	21	20	19	18	17	17
148	97	95	92	90	87	85	82	80	78	76	73	71	69	67	65	63	61	60	58	56	54	53	51	49	48	46	45	43	42	40	39	38	36	35	34	32	31	30	29	28	26	25	24	23	22	21	20	19	18	17
150	98	95	92	90	87	85	82	80	78	76	74	72	70	68	66	64	62	60	58	57	55	53	51	49	48	46	45	43	42	41	39	38	37	36	34	33	31	30	29	28	27	26	25	24	23	22	21	20	19	18

TABLE 2.—*Relative humidity table for use with wet-bulb and dry-bulb thermometers*—Continued

Temperature of dry bulb (° F.)	Difference between wet-bulb and dry-bulb thermometers, in degrees Fahrenheit: 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
152	98	95	93	90	88	85	83	81	79	76	74	72	70	68	66	64	62	60	59	57	55	53	52	50	48	47	46	44	42	41	40	39	37	36	35	33	32	31	30	29	28	26	25	24	23	22	21	20	19	19
154	98	95	93	90	88	85	83	81	79	77	74	72	70	68	66	65	63	61	59	57	56	54	52	50	49	47	46	44	43	42	40	39	38	37	35	34	33	32	30	29	28	27	26	25	24	23	22	21	20	19
156	98	95	93	90	88	85	83	81	79	77	74	72	71	69	67	65	63	61	59	58	56	54	53	51	49	48	46	45	43	42	41	40	38	37	36	34	33	32	31	30	29	28	27	25	24	23	23	22	21	20
158	98	95	93	90	88	86	83	81	79	77	75	73	71	69	67	65	63	61	60	58	56	55	53	51	50	48	47	45	44	43	41	40	39	38	36	35	34	33	31	30	29	28	27	26	25	24	23	22	21	20
160	98	95	93	90	88	86	83	81	79	77	75	73	71	69	67	65	64	62	60	58	57	55	53	52	50	49	47	46	44	43	42	41	39	38	37	35	34	33	32	31	30	29	28	27	25	24	24	23	22	21
162	98	95	93	90	88	86	84	82	80	77	75	73	71	69	68	66	64	62	60	59	57	55	54	52	51	49	47	46	45	44	42	41	40	39	37	36	35	34	32	31	30	29	28	27	26	25	24	23	22	22
164	98	95	93	91	88	86	84	82	80	78	75	73	72	70	68	66	64	62	61	59	58	56	54	52	51	49	48	47	45	44	43	41	40	39	38	36	35	34	33	32	31	30	29	28	26	25	25	24	23	22
166	98	95	93	91	88	86	84	82	80	78	76	74	72	70	68	66	65	63	61	59	58	56	54	53	51	50	48	47	45	44	43	42	41	39	38	37	36	35	33	32	31	30	29	28	27	26	25	24	23	23
168	98	95	93	91	88	86	84	82	80	78	76	74	72	70	68	67	65	63	61	60	58	56	55	53	52	50	49	47	46	45	43	42	41	40	39	37	36	35	34	33	32	31	30	29	28	27	26	25	24	23
170	98	95	93	91	89	86	84	82	80	78	76	74	72	70	69	67	65	63	62	60	59	57	55	53	52	51	49	48	47	45	44	43	41	40	39	38	37	35	34	33	32	31	30	29	28	27	26	25	24	24
172	98	95	93	91	89	86	84	82	81	78	76	74	73	71	69	67	66	64	62	60	59	57	55	54	53	51	50	48	47	46	45	43	42	41	39	38	37	36	35	34	33	32	31	30	28	27	26	26	25	24
174	98	95	93	91	89	87	84	83	81	78	76	75	73	71	69	67	66	64	62	61	59	57	56	54	53	51	50	49	47	46	45	43	42	41	40	39	37	36	35	34	33	32	31	30	29	28	27	26	25	24
176	98	96	94	91	89	87	85	83	81	79	77	75	73	71	70	68	66	64	63	61	60	58	56	55	53	52	50	49	48	46	45	44	43	42	40	39	38	37	36	35	34	33	32	31	29	28	27	27	26	25
178	98	96	94	91	89	87	85	83	81	79	77	75	73	72	70	68	66	64	63	61	60	58	56	55	54	52	51	49	48	47	46	44	43	42	41	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25
180	98	96	94	91	89	87	85	83	81	79	77	75	73	72	70	68	67	65	63	62	60	58	57	55	54	52	51	50	48	47	46	45	43	42	41	40	39	38	36	35	35	34	33	31	30	29	28	27	27	26
182	98	96	94	91	89	87	85	83	81	79	77	75	74	72	70	68	67	65	63	62	60	59	57	56	54	53	51	50	49	48	46	45	44	43	42	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26
184	98	96	94	92	89	87	85	83	82	79	77	76	74	72	70	69	67	65	64	62	61	59	57	56	55	53	52	50	49	48	47	45	44	43	42	41	39	38	37	36	35	34	33	32	31	30	29	28	27	27
186	98	96	94	92	90	87	85	83	82	80	78	76	74	72	71	69	67	66	64	62	61	59	58	56	55	53	52	51	49	48	47	46	44	43	42	41	40	39	38	37	36	35	34	33	32	30	30	29	28	27
188	98	96	94	92	90	87	85	84	82	80	78	76	74	73	71	69	68	66	64	63	62	59	58	57	55	54	52	51	50	49	47	46	45	44	43	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27
190	98	96	94	92	90	88	85	84	82	80	78	76	75	73	71	69	68	66	65	63	62	60	58	57	56	54	53	51	50	49	48	46	45	44	43	42	41	39	38	37	36	35	34	33	32	31	30	30	29	28
200	98	96	94	92	90	88	86	84	82	80	79	77	75	74	72	70	69	67	66	64	63	61	60	58	57	55	54	53	52	51	49	48	47	46	45	43	42	41	40	39	38	37	36	35	34	33	32	32	31	30
210	98	96	94	92	90	88	86	85	83	81	79	78	76	75	73	71	70	68	67	65	64	63	61	60	59	57	56	54	53	52	51	50	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	32
220	[1]98	[1]96	[1]94	[1]92	[1]91	[1]89	[1]87	[2]85	83	82	80	78	77	75	74	72	71	69	68	66	65	64	62	61	60	58	57	56	54	53	52	51	50	48	47	46	45	44	43	42	41	41	39	39	38	37	36	35	34	33

[1] Possible only at pressures higher than normal atmosphere.
[2] Superheated steam, at normal atmospheric pressure, no air present. At lower humidities air is mixed with the water vapor.

MOISTURE AND SHRINKAGE

Shrinkage of wood takes place only in conjunction with a loss of moisture,[9] and, conversely, swelling of wood is a result of the absorption of moisture. Some loss of moisture, however, is not accompanied by shrinkage. As wood dries it first gives up only its free water, leaving the moisture in the saturated cell walls undisturbed until the cell cavities have become empty, and wood does not start to shrink until the cell walls themselves begin to lose moisture.

FIBER-SATURATION POINT

The condition in which the cell cavities are entirely empty, with the cell walls still saturated throughout, is thus an important point in drying. It is known as the "fiber-saturation point." The moisture content at which this condition occurs varies from 20 to 35 per cent, but for most species it is between 25 and 30 per cent. In actual practice, of course, the cells near the surface of a piece of wood dry below the fiber-saturation point before those in the interior reach it. Then, even though the average moisture content of the whole piece may be above the fiber-saturation point, the outer portion tends to shrink, while the interior does not; in fact, the interior resists the shrinkage pressure of the outer portion. Such a state is often the cause of serious drying troubles.

CHARACTERISTIC SHRINKAGE VALUES

The recently revised figures in Table 3[10] indicate the volumetric, radial, and tangential shrinkages of a number of species of commercial importance. Volumetric shrinkage, as the name shows, is the reduction in the volume of a piece as it dries below the fiber-saturation point. Radial shrinkage, for example, is the reduction in width of a quarter-sawed board as it dries. (Fig. 2.) Tangential shrinkage similarly is the reduction in width of a flat-sawed board. The shrinkage values in the table, which are based on the green dimensions, are expressed as percentages. They represent the averages of measurements of 1 by 4 by 1 inch specimens in drying from the green condition to the oven-dried condition. To approximate the shrinkage from the green to an air-dry condition of 12 to 15 per cent moisture content, the tabular percentages should be multiplied by one-half. Likewise, the shrinkage from the green condition to a kiln-dried condition of 5 per cent moisture content may be estimated as about four-fifths of the tabular percentages. For example, the average tangential shrinkage of red gum is 9.9 per cent when it is dried from the green to the oven-dry condition. Thus an average 10-inch plain-sawed green board would shrink about 1 inch if oven dried, about one-half inch if dried to 12 or 15 per cent moisture content, and about three-quarters of an inch if dried to approximately 5 per cent moisture content.

In using figures like those of Table 3, it should be borne in mind that shrinkage is an extremely variable property, one that is in-

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[9] In common usage "moisture" means water, often water having small amounts of minerals or of acids in solution; this meaning is sufficient for the present purpose.

[10] The names of species of wood in the tables following are the standard common names given in the Check List of the Forest Trees of the United States (2).

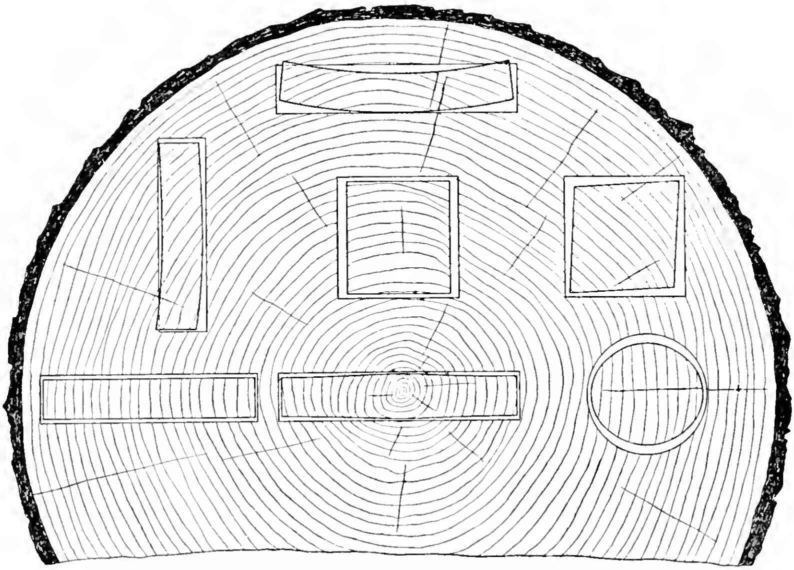

FIGURE 2.—Characteristic shrinkage and distortion of flats, squares, and rounds as affected by the direction of the annual rings. Tangential shrinkage is about twice as great as radial

fluenced by the density, the size, and the shape of the specimen and also by the drying conditions to which the specimen is exposed.

MOISTURE CONTENT AND FINAL USE

TABLE 3.—*Average shrinkages of clear wood of species grown in the United States, during drying from the green to the oven-dry condition, expressed in percentage of the green dimensions,*[1] *and average specific-gravity and weight values*

HARDWOODS (BROAD-LEAVED SPECIES)

Common and botanical names of species of wood	Shrinkage (measured values)			Ratio of tangential to radial shrinkage	Specific gravity when oven-dry based on volume when green	Weight per cubic foot—	
	Volumetric	Radial	Tangential			When green	At about 12 per cent moisture content
	Per cent	*Per cent*	*Per cent*			*Pounds*	*Pounds*
Alder, red (Alnus rubra)	12.6	4.4	7.3	1.66	0.37	46	28
Apple (Malus pumila var.)	17.6	5.6	10.1	1.80	.61	55	47
Ash, Biltmore white (Fraxinus biltmoreana)	12.6	4.2	6.9	1.64	.51	45	38
Ash, black (Fraxinus nigra)	15.2	5.0	7.8	1.56	.46	53	34
Ash, blue (Fraxinus quadrangulata)	11.7	3.9	6.5	1.67	.53	46	40
Ash, green (Fraxinus pennsylvanica lanceolata)	12.5	4.6	7.1	1.54	.53	49	40
Ash, Oregon (Fraxinus oregona)	13.2	4.1	8.1	1.98	.50	46	38
Ash, pumpkin (Fraxinus profunda)	12.0	3.7	6.3	1.70	.48	46	36
Ash, white (Fraxinus americana)	13.3	4.9	7.9	1.61	.55	48	42
Ashes, commercial white (average of four species [2])	12.8	4.6	7.5	1.63	.54	48	41
Aspen (Populus tremuloides)	11.5	3.5	6.7	1.91	.35	43	27

[1] Radial and tangential shrinkage values are based on width measurements of small clear pieces 1 inch thick, 4 inches wide, and 1 inch along the grain; volumetric values are based on pieces 2 by 2 inches in cross section and 6 inches long.

[2] Fraxinus biltmoreana, F. quadrangulata, F. pennsylvanica lanceolata, and F. americana.

TABLE 3.—*Average shrinkages of clear wood of species grown in the United States, etc.*—Continued

HARDWOODS (BROAD-LEAVED SPECIES)

Common and botanical names of species of wood	Shrinkage (measured values)			Ratio of tangential to radial shrinkage	Specific gravity when oven-dry based on volume when green	Weight per cubic foot—	
	Volumetric	Radial	Tangential			When green	At about 12 per cent moisture content
	Per cent	*Per cent*	*Per cent*			*Pounds*	*Pounds*
Aspen, largetooth (Populus grandidentata)	11.8	3.3	7.9	2.39	0.35	43	27
Basswood (Tilia glabra)	15.8	6.6	9.3	1.41	.32	41	26
Beech (Fagus grandifolia)	16.3	5.1	11.0	2.16	.56	54	45
Beech, blue (Carpinus caroliniana)	19.1	5.7	11.4	2.00	.58	53	48
Birch, Alaska white (Betula neoalaskana)	16.7	6.5	9.9	1.52	.49	48	38
Birch, gray (Betula populifolia)	14.7	5.2	----	----	.45	46	35
Birch, paper (Betula papyrifera)	16.2	6.3	8.6	1.37	.48	50	39
Birch, sweet (Betula lenta)	15.6	6.5	8.5	1.31	.60	57	46
Birch, yellow (Betula lutea)	16.7	7.2	9.2	1.28	.55	57	43
Blackwood (Avicennia nitida)	15.6	6.2	9.7	1.56	.83	74	58
Buckeye, yellow (Aesculus octandra)	12.0	3.5	7.8	2.23	.33	49	25
Butternut (Juglans cinerea)	10.2	3.3	6.1	1.85	.36	46	27
Buttonwood (Conocarpus erecta)	14.6	5.4	8.5	1.57	.69	64	50
Cascara (Rhamnus purshiana)	7.6	3.2	4.6	1.44	.50	50	36
Catalpa, hardy (Catalpa speciosa)	7.3	2.5	4.9	1.96	.38	41	29
Cherry, black (Prunus serotina)	11.5	3.7	7.1	1.92	.47	46	35
Cherry, pin (Prunus pennsylvanica)	12.8	2.8	10.3	3.68	.36	33	28
Chestnut (Castanea dentata)	11.6	3.4	6.7	1.97	.40	55	30
Chinquapin, golden (Castanopsis chrysophylla)	13.2	4.6	7.4	1.61	.42	61	32
Cottonwood, black (Populus trichocarpa)	12.4	3.6	8.6	2.39	.32	46	24
Cottonwood, eastern (Populus deltoides)	14.1	3.9	9.2	2.36	.37	49	28
Dogwood (Cornus florida)	19.9	7.1	11.3	1.59	.64	64	51
Dogwood, Pacific (Cornus nuttalli)	17.2	6.4	9.6	1.50	.58	55	45
Elder, blueberry (Sambucus coerulea)	15.6	4.4	9.0	2.05	.46	65	36
Elm, American (Ulmus americana)	14.6	4.2	9.5	2.26	.46	54	36
Elm, rock (Ulmus racemosa)	14.1	4.8	8.1	1.69	.57	54	44
Elm, slippery (Ulmus fulva)	13.8	4.9	8.9	1.82	.48	56	37
Gum, black (Nyssa sylvatica)	13.9	4.4	7.7	1.75	.46	45	35
Gum, blue (Eucalyptus globulus)	22.5	7.6	15.3	2.01	.62	70	52
Gum, red (Liquidambar styraciflua)	15.0	5.2	9.9	1.90	.44	50	34
Gum, tupelo (Nyssa aquatica)	12.5	4.2	7.6	1.81	.46	56	35
Gumbo-limbo (Bursera simaruba)	8.6	2.3	3.6	1.57	.30	38	22
Hackberry (Celtis occidentalis)	13.8	4.8	8.9	1.85	.49	50	37
Hickory, bigleaf shagbark (Hicoria laciniosa)	19.2	7.6	12.6	1.66	.62	62	48
Hickory, mockernut (Hickoria alba)	17.9	7.8	11.0	1.41	.64	64	51
Hickory, pignut (Hicoria glabra)	17.9	7.2	11.5	1.60	.66	64	53
Hickory, shagbark (Hicoria ovata)	16.7	7.0	10.5	1.50	.64	64	51
Hickories, pecan (average of four species [3])	13.6	4.9	8.9	1.82	.59	62	45
Hickories, true (average of four species [4])	17.9	7.3	11.4	1.56	.65	63	51
Hickories, pecan and true (average of eight species[5])	17.7	7.2	11.3	1.57	.64	63	50
Holly (Ilex opaca)	16.2	4.5	9.5	2.11	.50	57	40
Hop-hornbeam (Ostrya virginiana)	18.6	8.2	9.6	1.17	.63	60	50
Inkwood (Exothea paniculata)	18.8	6.6	10.9	1.65	.73	71	56
Ironwood, black (Krugiodendron ferreum)	11.6	6.2	8.0	1.29	1.04	86	80
Laurel, mountain (Kalmia latifolia)	14.4	5.6	8.8	1.57	.62	62	48
Locust, black (Robinia pseudoacacia)	9.8	4.4	6.9	1.57	.66	58	48
Locust, honey (Gleditsia triacanthos)	10.8	4.2	6.6	1.57	.60	61	44
Madroño (Arbutus menziesii)	17.4	5.4	11.9	2.20	.58	60	46
Magnolia, cucumber (Magnolia acuminata)	13.6	5.2	8.8	1.69	.44	49	34
Magnolia, evergreen (Magnolia grandiflora)	12.3	5.4	6.6	1.22	.46	62	35
Magnolia, mountain (Magnolia fraseri)	13.0	4.4	7.5	1.70	.40	47	31
Mangrove (Rhizophora mangle)	15.8	5.4	----	----	.89	77	67
Maple, bigleaf (Acer macrophyllum)	11.6	3.7	7.1	1.92	.44	47	34
Maple, black (Acer nigrum)	14.0	4.8	9.3	1.94	.52	54	40
Maple, red (Acer rubrum)	13.1	4.0	8.2	2.05	.49	50	38
Maple, silver (Acer saccharinum)	12.0	3.0	7.2	2.40	.44	45	33
Maple, striped (Acer pennsylvanicum)	12.3	3.2	8.6	2.69	.44	37	32
Maple, sugar (Acer saccharum)	14.9	4.9	9.5	1.94	.57	56	44

[3] Hicoria cordiformis, H. myristicaeformis, H. aquatica, and H. pecan.
[4] Hicoria laciniosa, H. alba, H. glabra, and H. ovata.
[5] Species under footnotes 3 and 4 combined.

TABLE 3.—*Average shrinkages of clear wood of species grown in the United States, etc.*—Continued

HARDWOODS (BROAD-LEAVED SPECIES)

Common and botanical names of species of wood	Shrinkage (measured values)			Ratio of tangential to radial shrinkage	Specific gravity when oven-dry based on volume when green	Weight per cubic foot—	
	Volumetric	Radial	Tangential			When green	At about 12 per cent moisture content
	Per cent	*Per cent*	*Per cent*			*Pounds*	*Pounds*
Mastic (Sideroxylon foetidissimum)	11.7	6.1	7.5	1.23	0.89	77	65
Myrtle, Oregon (Umbellularia californica)	11.9	2.8	8.1	2.89	.51	54	39
Oak, black (Quercus velutina)	14.2	4.5	9.7	2.16	.56	63	43
Oak, bur (Quercus macrocarpa)	12.7	4.4	8.8	2.00	.58	62	45
Oak, California black (Quercus kelloggii)	12.1	3.6	6.6	1.83	.51	66	40
Oak, canyon live (Quercus chrysolepis)	16.2	5.4	9.5	1.76	.70	71	54
Oak, chestnut (Quercus montana)	16.7	5.5	9.7	1.76	.57	61	46
Oak, laurel (Quercus laurifolia)	19.0	4.0	9.9	2.48	.56	65	44
Oak, live (Quercus virginiana)	14.7	6.6	9.5	1.44	.81	76	62
Oak, Oregon white (Quercus garryana)	13.4	4.2	9.0	2.14	.64	69	51
Oak, pin (Quercus palustris)	14.5	4.3	9.5	2.21	.58	63	44
Oak, post (Quercus stellata)	16.2	5.4	9.8	1.81	.60	63	47
Oak, red (Quercus borealis)	13.5	4.0	8.2	2.05	.56	63	44
Oak, Rocky Mountain white (Quercus utahensis)	12.5	4.1	7.2	1.76	.62	62	51
Oak, scarlet (Quercus coccinea)	13.8	4.6	9.7	2.11	.60	62	47
Oak, southern red (Quercus rubra)	16.3	4.5	8.7	1.93	.52	62	41
Oak, swamp red (Quercus rubra pagodaefolia)	16.4	5.2	10.8	2.08	.61	68	48
Oak, swamp chestnut (Quercus prinus)	19.4	5.9	9.2	1.56	.60	65	47
Oak, swamp white (Quercus bicolor)	17.7	5.5	10.6	1.93	.64	69	50
Oak, water (Quercus nigra)	16.4	4.2	9.3	2.21	.56	63	44
Oak, white (Quercus alba)	15.8	5.3	9.0	1.70	.60	62	48
Oak, willow (Quercus phellos)	18.9	5.0	9.6	1.92	.56	67	49
Oaks, commercial red (average of 9 species [6])	14.8	4.2	9.0	2.14	.56	64	44
Oaks, commercial white (average of 6 species [7])	16.0	5.3	9.3	1.75	.59	63	47
Oaks, commercial red and white (average of 15 species [8])	15.3	4.7	9.1	1.94	.57	63	45
Osage-orange (Toxylon pomiferum)	8.9	------	------	------	.76	62	------
Palmetto, cabbage (Sabal palmetto)	25.0	------	------	------	.37	54	27
Paradise-tree (Simarouba glauca)	8.6	2.2	5.2	2.36	.33	37	24
Pecan (Hicoria pecan)	13.6	4.9	8.9	1.82	.60	61	47
Persimmon (Diospyros virginiana)	18.3	7.5	10.8	1.44	.64	63	52
Pigeon-plum (Coccolobis laurifolia)	15.7	4.4	7.8	1.77	.77	73	55
Poisonwood (Metopium toxiferum)	11.6	4.2	7.2	1.71	.51	54	37
Poplar, balsam (Populus balsamifera)	10.5	3.0	7.1	2.37	.30	40	23
Poplar, yellow (Liriodendron tulipifera)	12.3	4.0	7.1	1.78	.38	38	28
Rhododendron, great (Rhododendron maximum)	16.2	6.3	8.7	1.38	.50	62	40
Sassafras (Sassafras variifolium)	10.3	4.0	6.2	1.55	.42	44	32
Serviceberry (Amelanchier canadensis)	18.7	6.7	10.8	1.61	.66	61	52
Silverbell (Halesia carolina)	12.6	3.8	7.6	2.00	.42	44	32
Sourwood (Oxydendrum arboreum)	15.2	6.3	8.9	1.41	.50	53	38
Stopper, red (Eugenia confusa)	13.3	6.2	9.1	1.47	.83	73	61
Sugarberry (Celtis laevigata)	12.7	5.0	7.3	1.46	.47	48	36
Sycamore (Platanus occidentalis)	14.2	5.1	7.6	1.49	.46	52	35
Walnut, black (Juglans nigra)	11.3	5.2	7.1	1.37	.51	58	39
Walnut, little (Juglans rupestris)	10.7	4.4	4.6	1.05	.53	55	40
Willow, black (Salix nigra)	13.8	2.5	7.8	3.12	.34	50	26
Willow, western black (Salix lasiandra)	13.8	2.9	9.0	3.10	.39	50	31
Witch-hazel (Hamamelis virginiana)	18.8	------	------	------	.56	59	43

SOFTWOODS (CONIFERS)

Cedar, Alaska (Chamaecyparis nootkatensis)	9.2	2.8	6.0	2.14	0.42	36	31
Cedar, incense (Libocedrus decurrens)	7.6	3.3	5.7	1.73	.35	45	26
Cedar, Port Orford (Chamaecyparis lawsoniana)	10.1	4.6	6.9	1.50	.40	36	29

[6] Quercus velutina, Q. laurifolia, Q. palustris, Q. borealis, Q. coccinea, Q. rubra, Q. rubra pagodaefolia, Q. nigra, and Q. phellos.
[7] Quercus macrocarpa, Q. montana, Q. stellata, Q. prinus, Q. bicolor, and Q. alba.
[8] Species under footnotes 6 and 7 combined.

TABLE 3.—*Average shrinkages of clear wood of species grown in the United States, etc.*—Continued

SOFTWOODS (CONIFERS)

Common and botanical names of species of wood	Shrinkage (measured values)			Ratio of tangential to radial shrinkage	Specific gravity when oven-dry based on volume when green	Weight per cubic foot—	
	Volumetric	Radial	Tangential			When green	At about 12 per cent moisture content
	Per cent	*Per cent*	*Per cent*			*Pounds*	*Pounds*
Cedar, eastern red (Juniperus virginiana)	7.8	3.1	4.7	1.52	0.44	37	33
Cedar, western red (Thuja plicata)	7.7	2.4	5.0	2.08	.31	27	23
Cedar, northern white (Thuja occidentalis)	7.0	2.1	4.7	2.24	.29	28	22
Cedar, southern white (Chamaecyparis thyoides)	8.4	2.8	5.2	1.86	.31	26	23
Cypress, southern (Taxodium distichum)	10.5	3.8	6.2	1.63	.42	50	32
Douglas fir (Pseudotsuga taxifolia) (coast type)	11.8	5.0	7.8	1.56	.45	38	34
Douglas fir (Pseudotsuga taxifolia) (Rocky Mountain type)	10.9	3.6	6.2	1.72	.40	35	30
Fir, alpine (Abies lasiocarpa)	9.0	2.5	7.1	2.84	.31	28	23
Fir, balsam (Abies balsamea)	10.8	2.8	6.6	2.36	.34	45	26
Fir, corkbark (Abies arizonica)	9.0	2.8	7.4	2.64	.28	29	21
Fir, lowland white (Abies grandis)	10.6	3.2	7.2	2.25	.37	44	28
Fir, noble (Abies nobilis)	12.5	4.5	8.3	1.84	.35	30	26
Fir, California red (Abies magnifica)	11.8	3.8	6.9	1.82	.37	48	27
Fir, silver (Abies amabilis)	14.1	4.5	10.0	2.22	.35	36	27
Fir, white (Abies concolor)	9.4	3.2	7.0	2.19	.35	47	26
Firs, white (average of four species [9])	10.9	3.8	7.9	2.08	.35	41	26
Hemlock, eastern (Tsuga canadensis)	9.7	3.0	6.8	2.27	.38	50	28
Hemlock, mountain (Tsuga mertensiana)	11.4	4.4	7.4	1.68	.43	44	33
Hemlock, western (Tsuga heterophylla)	11.9	4.3	7.9	1.84	.38	41	29
Juniper, alligator (Juniperus pachyphloea)	7.8	2.7	3.6	1.33	.48	42	36
Larch, western (Larix occidentalis)	13.2	4.2	8.1	1.93	.48	48	36
Pine, jack (Pinus banksiana)	10.4	3.4	6.5	1.91	.39	50	30
Pine, jeffrey (Pinus jeffreyi)	9.9	4.4	6.7	1.52	.37	47	28
Pine, limber (Pinus flexilis)	8.2	2.4	5.1	2.13	.37	39	28
Pine, loblolly (Pinus taeda)	12.6	5.5	7.5	1.36	.50	54	38
Pine, lodgepole (Pinus contorta)	11.5	4.5	6.7	1.49	.38	39	29
Pine, longleaf (Pinus palustris)	12.3	5.3	7.5	1.42	.55	50	41
Pine, mountain (Pinus pungens)	10.9	3.4	6.8	2.00	.49	54	37
Pine, northern white (Pinus strobus)	8.2	2.3	6.0	2.61	.34	36	25
Pine, Norway (Pinus resinosa)	11.5	4.6	7.2	1.57	.44	42	34
Pine, pitch (Pinus rigida)	10.9	4.0	7.1	1.78	.45	50	34
Pine, pond (Pinus rigida serotina)	11.2	5.1	7.1	1.39	.50	49	38
Pine, sand (Pinus clausa)	10.0	3.9	7.3	1.87	.45	38	34
Pine, shortleaf (Pinus echinata)	12.6	5.1	8.2	1.61	.49	51	38
Pine, slash (Pinus caribaea)	12.7	5.8	8.2	1.41	.64	56	48
Pine, sugar (Pinus lambertiana)	7.9	2.9	5.6	1.93	.35	51	25
Pine, western white (Pinus monticola)	11.8	4.1	7.4	1.81	.36	35	27
Pine, western yellow (Pinus ponderosa)	9.6	3.9	6.3	1.62	.38	45	28
Piñon (Pinus edulis)	9.9	4.6	5.2	1.13	.50	51	37
Redwood [10] (Sequoia sempervirens)	6.3	2.7	4.2	1.56	.41	55	30
Spruce, black (Picea mariana)	11.3	4.1	6.8	1.66	.38	32	28
Spruce, Engelmann (Picea engelmannii)	10.4	3.4	6.6	1.94	.31	39	23
Spruce, red (Picea rubra)	11.8	3.8	7.8	2.05	.38	34	28
Spruce, Sitka (Picea sitchensis)	11.5	4.3	7.5	1.74	.37	33	28
Spruce, white (Picea glauca)	13.7	4.7	8.2	1.74	.37	35	28
Spruces (average of red, white, and Sitka [11])	12.1	4.3	7.7	1.79	.37	34	28
Tamarack (Larix laricina)	13.6	3.7	7.4	2.00	.49	47	37
Yew, Pacific (Taxus brevifolia)	9.7	4.0	5.4	1.35	.60	54	44

[9] Abies grandis, A. nobilis, A. amabilis, and A. concolor.

[10] The trees on which these values are based were somewhat higher in density than the general average for the species. Hence it is very probable that further tests, which are now under way, will slightly lower the present figures.

[11] Picea rubra, P. sitchensis, and P. glauca.

As previously mentioned, green wood is seasoned to remove a part of the moisture that it contains. It thus becomes better fitted for commercial use; the tendency to shrink, warp, and check after being placed in service is reduced, it is less subject to stain, mold, and insect attack, and the loss in weight results in lower freight charges and reduces other handling costs.

The fact that wood below the fiber-saturation point shrinks and swells with changes in moisture content makes it highly desirable, in the seasoning process, to obtain for the wood a final moisture content that will be suitable for the condition of ultimate use. In the past this matter has been given too little consideration, but the necessity for attention to this phase of drying is becoming more and more apparent.

The moisture content of lumber dried even according to the best air-seasoning practice varies somewhat. Neglecting this condition, which can be corrected by heated storage or similar means, absolute attainment of a proper final moisture content for all uses is not feasible in commercial work, both on account of the diverse purposes for which wood is employed and the wide range of atmospheric conditions to which it is subjected. Wood thoroughly air-dry at Galveston, Tex., for example, is likely to have a moisture content somewhat greater than that of air-dry wood in the general Middle West States and considerably greater than that customary for interior woodwork in heated buildings. Such conditions indicate clearly that the final moisture-content problem is a difficult one and also emphasize its importance. To solve the problem it is often necessary to kiln-dry the wood instead of air-drying it, or in addition to air-drying it.

GENERAL PRINCIPLES OF DRYING WOOD

MOVEMENT OF MOISTURE IN WOOD

PRESENT KNOWLEDGE

Although the actual phenomena of drying wood are not yet understood in all their details, there is considerable knowledge that bears on the practical seasoning problem. As stated before, wood upon drying first loses its free water and then that which is contained in the cell walls. The moisture in the interior of a piece of wood can come to the surface only as a vapor moving along the capillary channels in the wood, after evaporating inside of the piece, or as a liquid moving either through the same channels or through the cell walls. Regardless of whether such moisture moves outward as a vapor, or as a liquid, or as both, on account of the nature of wood structure the end grain of wood loses moisture more rapidly than the side grain does.

In a consideration of the air-seasoning process, a general understanding of the movement of moisture in wood is sufficient. It can be assumed that the moisture tends to distribute itself evenly through the wood, moving from the moist regions to the drier ones. The really important fact, however, is that the temperature and the humidity of the atmosphere at the surface of the wood are controlling factors, while circulation of the air is of extreme importance in maintaining and in modifying them.

EFFECT OF TEMPERATURE

The temperature of the air surrounding wood affects seasoning in a number of ways. Heat is consumed when evaporation takes place, and the ease of transfer of the heat from the air to its point of consumption increases with increase in temperature of the air entering the pile. The heat required for evaporation must be supplied by the air, adequate circulation of the air is required for such supply, and largely because of increased cooling effects local circulation in the pile is likely to be better at high temperatures than at low. As already pointed out, an increase in the temperature of the air increases its capacity to hold moisture and thus hastens evaporation. Below the fiber-saturation point a certain amount of heat is required to separate water from wood, the amount increasing as the wood becomes drier; air at a high temperature holds more heat, which it can give up for this purpose, than the same air at a low temperature.

The effects of the temperature of the surrounding air upon the drying process explain certain conditions encountered in air seasoning. For example, even during the coolest months of the year a comparatively rapid loss of moisture from bare wood occurs until a moisture content of about 30 per cent is reached. Then a rather abrupt decrease in the drying rate usually takes place.

EFFECT OF RELATIVE HUMIDITY

The relation of the relative humidity of the surrounding air to the moisture in wood has been discussed previously (p. 6). It was pointed out that this relationship determines the extent to which wood dries. At a given temperature, the relative humidity determines also the rate of drying. In general, other factors remaining constant, the lower the relative humidity the faster will drying take place, and, conversely, the higher the relative humidity the slower will be the drying. This is true because lowering the humidity reduces the moisture content of the wood at the surface, thus increasing the rate of movement of moisture toward the surface and consequently hastening the drying.

EFFECT OF CIRCULATION

Circulation also plays a large part in the seasoning process. As wood dries, the evaporation both uses up heat and increases the amount of moisture in the surrounding air. Hence circulation is required to supply the heat necessary for evaporation and also to remove the evaporated moisture. Circulation is thus a prime factor in the drying of wood by any method and is particularly important in air seasoning, because there it is the only essential factor that can be controlled to an appreciable extent. Further, when the circulation is sluggish, the air in direct contact with a green board is likely to be at a high relative humidity, perhaps even as high as 100 per cent. Obviously the relative humidity of the film of air immediately at the surface of the board has a major effect on the drying rate of the wood and, since this relative humidity is influenced directly by the rate of circulation, the importance of circulation is again evident.

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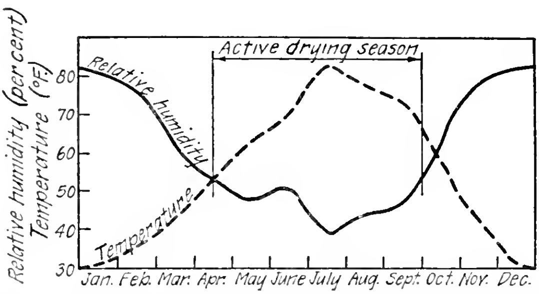
APPLICATION TO AIR SEASONING OF THE GENERAL PRINCIPLES OF DRYING WOOD

GENERAL CONDITIONS AT THE LUMBER PILE

The air seasoning of lumber, like any process for drying wood, is dependent upon the temperature, humidity, and circulation of the surrounding air. Consequently the regional climatic conditions,



A.—COMPARATIVE MONTHLY ATMOSPHERIC-TEMPERATURE AND RELATIVE-HUMIDITY CONDITIONS; PLOTTED AVERAGES OF THE VALUES READ DAILY AT 4 P.M.

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
150	120	100	100	90	75	50	75	225	225	225	200

B.—AVERAGE DRYING PERIODS (IN DAYS) REQUIRED FOR STOCK, PILED IN THE MONTHS INDICATED, TO REACH 15 PER CENT MOISTURE CONTENT; LOCAL VARIATION IN CONDITIONS MAY CAUSE A CONSIDERABLE DIFFERENCE FROM THE AVERAGE PERIOD

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
20	20	18	15	14	14	12½	13	14	15	20	20

C.—APPROXIMATE MOISTURE CONTENT OF THOROUGHLY AIR-DRY STOCK, EXPRESSED BY MONTHS AND IN PERCENTAGE OF WEIGHT OF OVEN-DRY WOOD

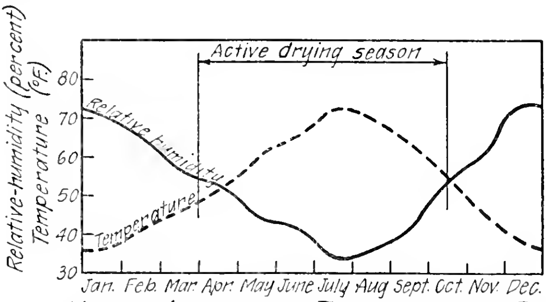
Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
2	–	–	–	–	–	–	–	1	2	2	2

D.—AVERAGE PICK-UP OF MOISTURE BY YARD STOCK DURING DIFFERENT MONTHS, EXPRESSED IN PERCENTAGE OF WEIGHT OF OVEN-DRY WOOD

FIGURE 3.—Graphic chart of major air-seasoning factors in the Inland Empire. The chart is based on average figures covering a period of two years and representing five yards drying 4/4-inch western white pine and western yellow pine stock. It indicates typical conditions for the region in general, but does not show the wide variation from the average that may obtain locally at any specific lumber plant

affected as they are by local factors such as elevation, topography, drainage, and water bodies, constitute the primary influences in air seasoning. Although efficient air-seasoning practice is designed to exert some control upon the drying conditions within the lumber pile, there is some relationship between these conditions and those outside. No matter what the yard methods, a warm, dry, and windy climate will cause faster drying and lower final moisture content than will cool, damp, and calm climatic conditions.

There is considerable variation in geographic and climatic factors among the various lumber-producing regions and also among yards in the same region. The influence of such natural conditions upon the air-seasoning process is illustrated in a broad way by the data presented in Figures 3 to 6, inclusive, which show the effect of different weather conditions upon actual seasoning in the western softwood regions. The moisture content for thoroughly air-dry



A.—COMPARATIVE MONTHLY ATMOSPHERIC-TEMPERATURE AND RELATIVE-HUMIDITY CONDITIONS; PLOTTED AVERAGES OF DAILY READINGS AT REPRESENTATIVE POINTS IN THE REGION

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
120	90	70	70	60	55	50	45	160	160	140	140

B.—AVERAGE DRYING PERIODS (IN DAYS) REQUIRED FOR 6/4-INCH STOCK, PILED IN THE MONTHS INDICATED, TO REACH 15 PER CENT MOISTURE CONTENT; LOCAL VARIATION IN CONDITIONS MAY CAUSE A CONSIDERABLE DIFFERENCE FROM THE AVERAGE PERIOD

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
20	18	16	14	12	10	9	9	10	12	16	18

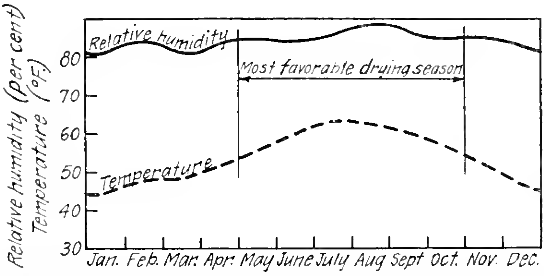
C.—APPROXIMATE MOISTURE CONTENT OF THOROUGHLY AIR-DRY STOCK, EXPRESSED BY MONTHS AND IN PERCENTAGE OF WEIGHT OF OVEN-DRY WOOD.

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
3	—	—	—	—	—	—	—	—	1	1½	2

D.—AVERAGE PICK-UP OF MOISTURE BY YARD STOCK DURING DIFFERENT MONTHS, EXPRESSED IN PERCENTAGE OF WEIGHT OF OVEN-DRY WOOD

FIGURE 4.—Graphic chart of major air-seasoning factors in the California pine region. The chart, which is based on the average of representative figures, indicates typical conditions for the region in general, but does not show the wide variation from the average that may obtain locally at any specific lumber plant

stock (C of figs. 3–6) indicated for each month is not to be considered as the equilibrium moisture content for the temperature and the relative humidity shown in the curves of the same chart (A of figs. 3–6), because the temperature and the relative humidity readings for each day represent only two observations, which are not sufficient in number to give true averages. The curves adapted from Department Bulletin No. 1425, however, do show the general trend in temperature and relative humidity from month to month. Even though these natural conditions must be largely accepted, a knowledge of them and recognition of their consequence in seasoning are essential in the intelligent selection of a yard site, in the proper laying out of the seasoning yard, and in the development of effective piling methods.



A.—COMPARATIVE MONTHLY ATMOSPHERIC-TEMPERATURE AND RELATIVE-HUMIDITY CONDITIONS; PLOTTED AVERAGES OF DAILY READINGS AT REPRESENTATIVE POINTS IN THE REGION

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
180	150	150	120	100	80	70	100	250	220	200	180

B.—AVERAGE DRYING PERIODS (IN DAYS) REQUIRED FOR 4/4-INCH STOCK, PILED IN THE MONTHS INDICATED, TO REACH 15 PER CENT MOISTURE CONTENT; LOCAL VARIATION IN CONDITIONS MAY CAUSE A CONSIDERABLE DIFFERENCE FROM THE AVERAGE PERIOD

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
24	25	22	20	18	16	15	15	16	17	19	21

C.—APPROXIMATE MOISTURE CONTENT OF THOROUGHLY AIR-DRY STOCK, EXPRESSED BY MONTHS AND IN PERCENTAGE OF WEIGHT OF OVEN-DRY WOOD

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
3	1	—	—	—	—	—	—	—	1	2	3

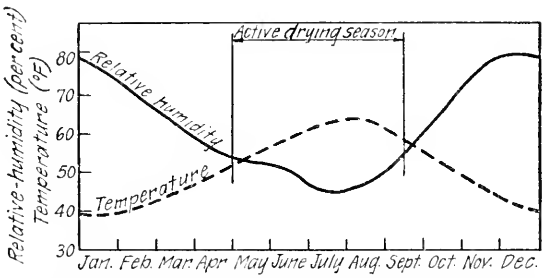
D.—AVERAGE PICK-UP OF MOISTURE BY YARD STOCK DURING DIFFERENT MONTHS, EXPRESSED IN PERCENTAGE OF WEIGHT OF OVEN-DRY WOOD

FIGURE 5.—Graphic chart of major air-seasoning factors in the redwood region. The chart, which is based on the averages of representative figures, indicates typical conditions for the region in general, but does not show the wide variation from the average that may obtain locally at any specific lumber plant

The aim of air-seasoning practice must be limited to employing the favorable natural elements to the greatest possible advantage and to minimizing the unfavorable factors as far as is practicable. The means for accomplishing this aim are brought out in the later and more detailed discussion of air-seasoning practice.

TEMPERATURE IN THE LUMBER PILE

Within the limits of existing climatic conditions, some indirect control of temperature in the lumber pile is possible. Through the provision of adequate means for circulation both in the yard and in the pile, the air cooled by evaporation is replaced by warmer air from the outside, thus increasing the temperature. Further, some heat is transmitted to the lumber from the direct rays of the sun, which reach at least a part of the pile during some portion of the



A.—COMPARATIVE MONTHLY ATMOSPHERIC-TEMPERATURE AND RELATIVE-HUMIDITY CONDITIONS; PLOTTED AVERAGES OF DAILY READINGS AT REPRESENTATIVE POINTS IN THE REGION

	Th'kness	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
To Reach 20 Per Cent Moisture Content	4/4	100	80	55	35	25	20	20	15	220	190	160	130
	8/4	110	90	65	45	35	30	30	25	230	200	170	140
To Reach 15 Per Cent Moisture Content	4/4	145	120	100	70	45	40	40	45	270	240	210	180
	8/4	165	140	115	90	60	55	55	320	290	260	230	200

B.—AVERAGE DRYING PERIODS (IN DAYS) REQUIRED FOR STOCK, PILED IN THE MONTHS INDICATED, TO REACH THE MOISTURE CONTENT SHOWN; LOCAL VARIATION IN CONDITIONS MAY CAUSE A DIFFERENCE OF 10 TO 20 DAYS FROM THE AVERAGE PERIOD

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
26	24	22	18	16	15	12	13	15	16	22	26

C.—APPROXIMATE MOISTURE CONTENT OF THOROUGHLY AIR-DRY 4/4-INCH STOCK, EXPRESSED BY MONTHS AND IN PERCENTAGE OF WEIGHT OF OVEN-DRY WOOD

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
—	—	—	—	—	—	—	—	2	2	2	2

D.—AVERAGE PICK-UP OF MOISTURE BY 4/4-INCH YARD STOCK DURING DIFFERENT MONTHS, EXPRESSED IN PERCENTAGE OF WEIGHT OF OVEN-DRY WOOD

FIGURE 6.—Graphic chart of major air-seasoning factors in the Douglas fir region. The chart, which is based on the averages of representatives figures, indicates typical conditions for the region in general, but does not show the wide variation from the average that may obtain locally at any specific lumber plant

day. The extent of the pile surface that receives direct sunlight, as well as the length of the daily period during which it is received, can be controlled to some extent by varying the spacings around the pile and changing the direction of the openings between piles.

HUMIDITY IN THE LUMBER PILE

Control of humidity conditions within the pile, as far as it is possible, also can be accomplished only by indirect means. Circulation, if it occurs, carries away the moist air resulting from seasoning and replaces it with air from the outside that contains less moisture. The regulation of temperature mentioned in the preceding paragraph also affects the relative humidity, since an increase of temperature means that the drying capacity of the air is increased.

CIRCULATION IN THE LUMBER PILE

The functions and the importance of circulation in air seasoning have been indicated in the discussions of temperature and humidity control. Circulation is the only drying factor that is subject to direct methods of control.

The movement of air in a lumber pile is the resultant of two general types of circulation. Horizontal circulation is caused primarily by the local wind currents. Vertical circulation, on the other hand, is an internal movement produced by evaporation and the resulting differences in temperature throughout the pile.

Horizontal circulation can be regulated to some extent by variations in yard layout, in foundation construction, and in piling methods. The arrangement and spacing of main alleys and rear alleys and the intervals between piles on the same alley affect the movement of the local air currents to a large extent. Likewise the clearance under the pile foundations exerts an appreciable influence. The actual inlet and outlet of the wind currents to and from the pile are greatly affected by the method of pile construction. For example, an increase in the thickness of the stickers materially assists in building up positive horizontal circulation.

Vertical circulation in a lumber pile is a seasoning factor of the utmost importance and hence should be thoroughly understood. As the green stock in a pile dries, the evaporation uses up heat, which is taken from the air in contact with the stock. This air, thus becoming cooler and consequently heavier, tends to drop [11] gradually toward the bottom of the pile. Methods of pile construction should therefore be designed to aid this natural movement, permitting as far as possible an unobstructed and continuous vertical flow of air. To secure the maximum benefits from vertical circulation, it must be adequate, not only at a single point but also entirely across the pile from one side to the other. This means that vertical air channels, well distributed, are essential.

The natural downward movement of cool, moist air in a lumber pile results in partial stagnation and slow drying in the lower section unless proper means are provided to insure the removal of such air. Thus horizontal circulation, particularly in the lower portion of the pile and beneath it, is a necessary adjunct to the vertical circulation. Such movement toward the outside of the pile results from external

[11] Such movement is in the general direction that normally obtains during the greater part of the time in which actual drying is taking place. During cool days, and especially during cool nights when the lumber is dry or practically so, the cooler outside air entering a warmer space within the pile may cause a temporary reversal of this downward movement.

wind currents and to a less degree from a natural outward flow in the lower portions of the pile, caused by the pressure of the downward movement. The outward flow can be aided materially by the control methods already discussed in connection with horizontal circulation.

There is much misconception as to the movement of air in a lumber pile. If the natural tendency of the air to drop toward the bottom of the pile is not fully appreciated and adequately recognized in the development of the entire air-seasoning practice, serious drying troubles are almost certain to develop. The drying in the lower

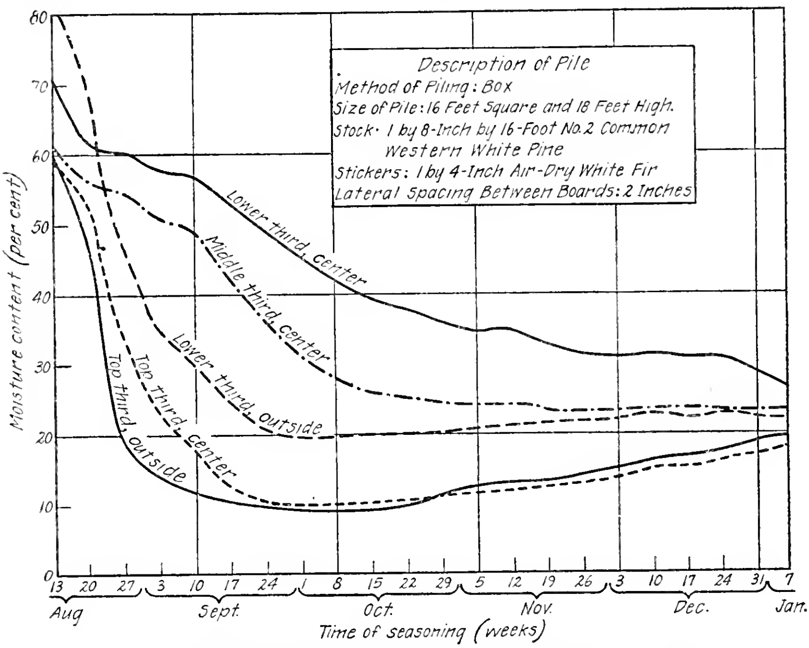


FIGURE 7.—Representative changes in moisture-content values in different parts of a typical pile of softwood yard lumber

part of the pile will then lag behind that in the other parts. As a result, the average drying time will be lengthened, a portion of the stock may never reach a thoroughly air-dry condition, and the liability of the development of stain and decay will be increased. Such a lag in drying is illustrated by Figure 7, taken from Department Bulletin No. 1425, which represents actual drying conditions in different parts of a common type of lumber pile.

SMOKE MACHINE

In studying the effect of wind, temperature, and method of piling on the direction and the rate of air movement in a lumber pile, it may be helpful to use a smoke machine. This apparatus may consist of two glass containers, each about 1¼ inches in diameter and 5 inches long, one of which is filled halfway with ammonium hydroxide (ammonia water; specific gravity 0.9) and the other with hydrochloric acid (specific gravity 1.19). The containers are provided with 2-hole rubber stoppers and are connected by a glass tube about one-fourth inch in outside diameter. By means of a rubber bulb air is blown into the upper part of one container, forcing the vapor there over to the similar space in the second container, where it unites with the vapor above the other liquid, thus forming ammonium chloride. This salt emerges as a white smoke. When the smoke is released in a current of air it is carried along with the current, thus making the air movement evident. For the sake of convenience the containers may be supported in a small wood block drilled with holes of the proper size and provided with a short handle. In some cases it is advantageous to connect several feet of 3/8-inch rubber hose to the discharge opening in the second rubber stopper, so that the smoke can be directed to any desired point. If the tubing becomes clogged, the ammonium chloride may be readily dissolved in water.

The Kiln Drying Handbook [12] illustrates a smoke machine of similar construction.

SEASONING DEFECTS AND THEIR CAUSES

The defects responsible for the depreciation incident to air seasoning are definitely related to the drying process itself or to the time element of that process. An explanation of their causes will permit a better appreciation of the possibility and the means of preventing them. These defects may be grouped as those resulting from shrinkage and those caused by the action of minute organisms that belong to a low form of plant life known as fungi.

In the first group are check, honeycomb, cup, bow, crook, twist, loosening of knots, and collapse. The second group includes stains and decay. Blue stain is the principal stain of economic importance in the air seasoning of many species, both hardwoods and softwoods, although brown stain (p. 29) is of some importance in certain softwoods. On account of the general climatic conditions in the West and the drying periods usually required there, decay need not be considered an air-seasoning defect in lumber in that region. In the South, on the other hand, both climatic and logging conditions are very conducive to the development of decay. All of the measures taken to reduce blue-stain development are also helpful in decay prevention.

DEFECTS RESULTING FROM SHRINKAGE

END AND SURFACE CHECKS

Lumber checks as a result of uneven shrinkage. Such shrinkage may be due to one or both of two causes, uneven drying and the inherent difference in the amounts of radial and tangential shrinkage of wood.

There are three common causes of uneven drying: (1) The end grain of wood gives off moisture more rapidly than the side grain; (2) surface layers dry faster than those in the interior, especially during the early stages of drying; (3) a portion of a board fully

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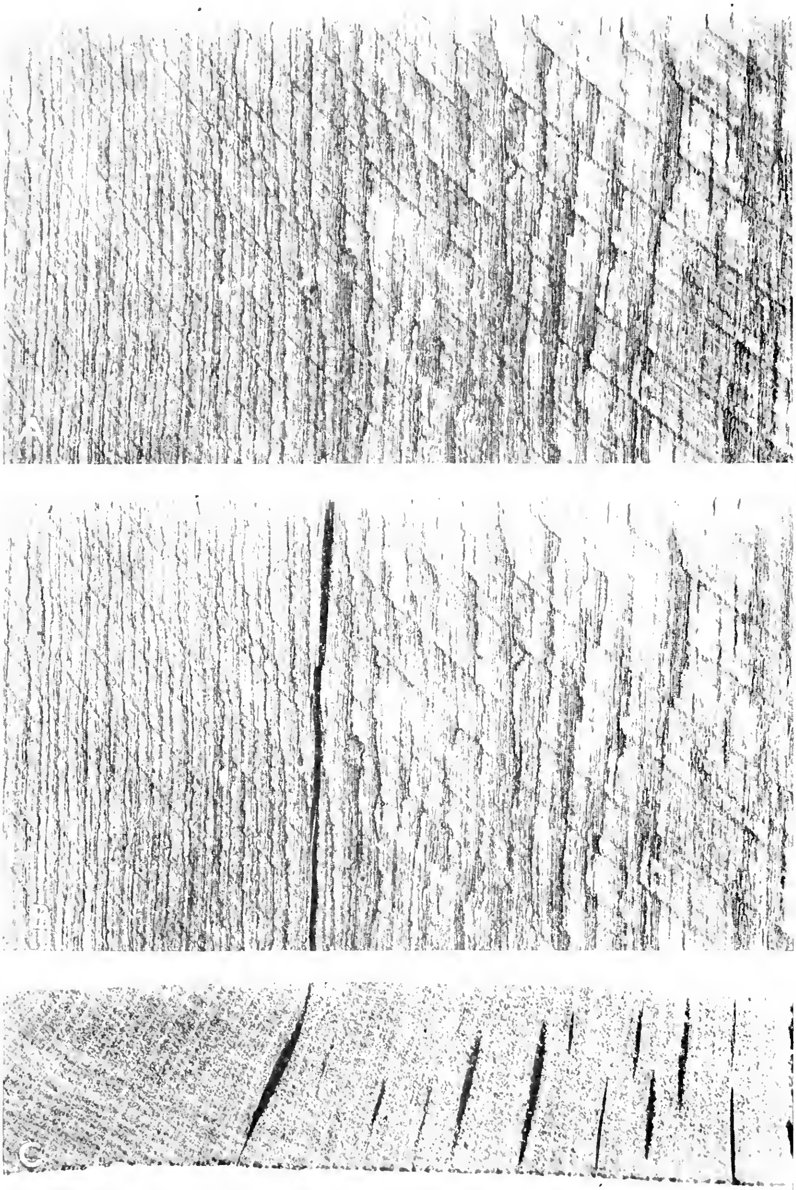
[12] See footnote 4.



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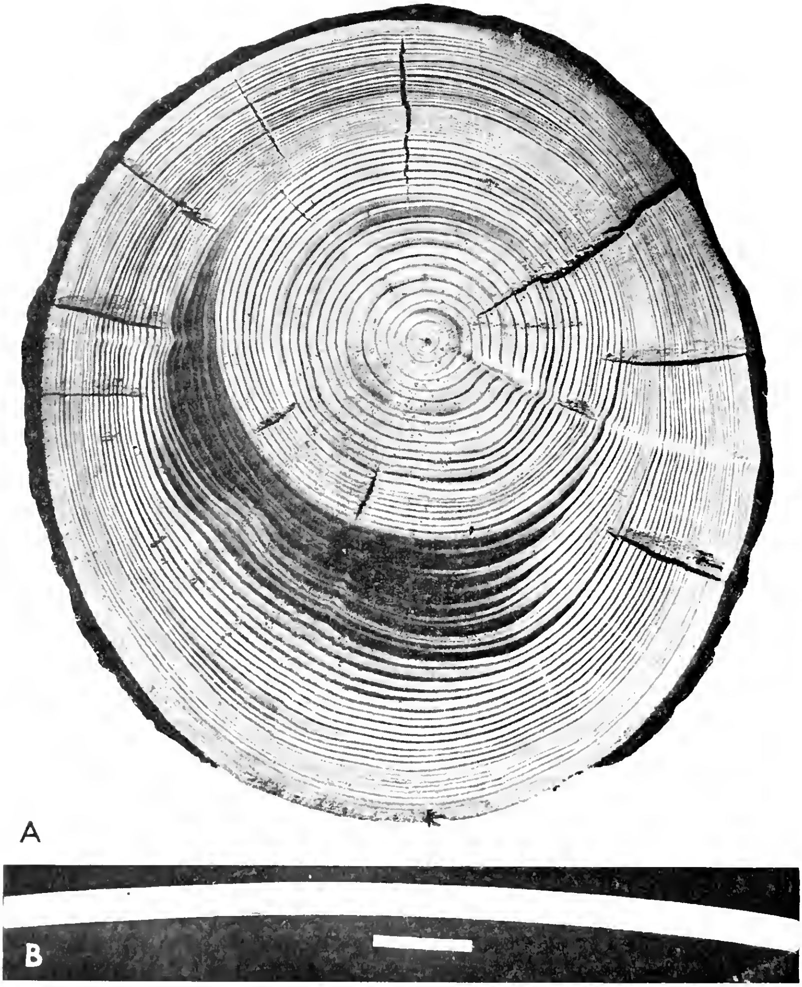
A surface check in a 6/4-inch hardwood board closed by compression of the surface fibers during the latter part of the seasoning period: A, Normal appearance of the surface; B, the sides of the check forced apart at one surface; C, cross section of the board at the check



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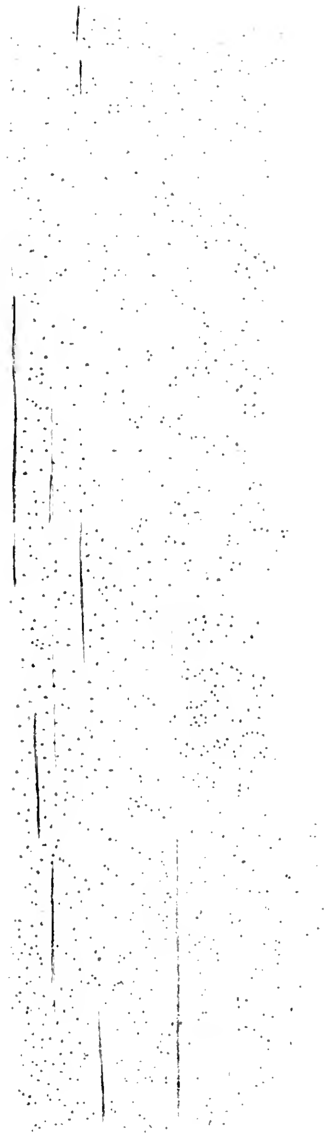
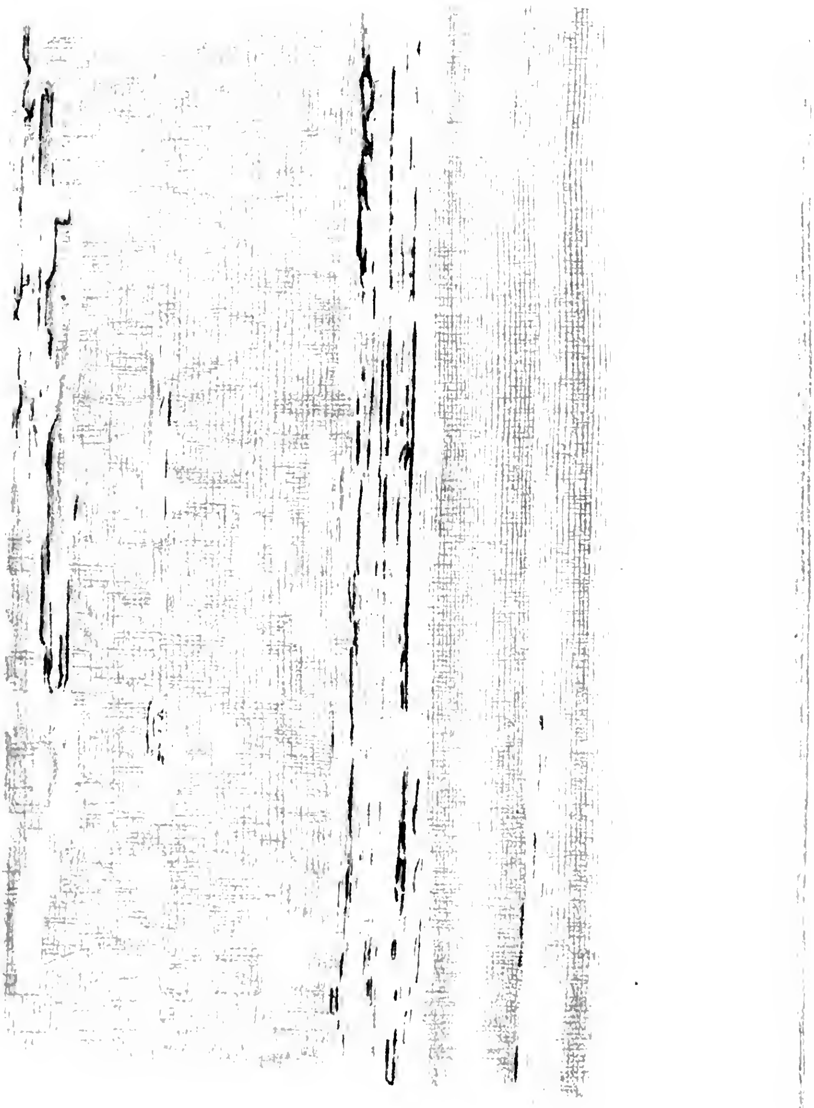
Compression wood: A, The dark, wide rings in the lower part of the cross section are compression wood; B, crook caused by the extreme longitudinal shrinkage of compression wood on the upper edge of a 2 by 4 inch stud. The 12-inch ruler indicates the length of the 8-foot stud



Blue stain in a conifer. The dark-blue specks are the ends of the wood rays. The pale orange-colored wood at the right is unstained heartwood



A section of damaged heartwood of a conifer. The typical decay illustrated is caused by the [illegible] fungus. The light-colored wood at the right is sound sapwood.

exposed to the drying effect of the air loses its moisture before an adjacent section not so exposed dries to the same extent.

Tangential shrinkage, the shrinkage across the width of plain-sawed stock, is on an average about twice as great as radial shrinkage, which is the shrinkage across the width of quarter-sawed stock. Table 3 gives the ratios of tangential to radial shrinkage for various commercial species.

The end checking of lumber during air seasoning is largely due to the uneven shrinkage caused by the exposed ends of the boards drying more rapidly than the adjoining portions. Not only does end grain give off its moisture more rapidly than side grain, but in addition portions of both the major side-grain surfaces, near or next to the ends, are kept from direct contact with the drying effect of the air by the stickers that cover them. It follows that two actions are necessary to minimize end checking: Ends of the stock should be shaded to decrease the rate of end drying, and the area of the board faces not exposed to the air should be reduced as far as practicable. As explained on page 40, end coating may be used instead of shading in order to reduce end checking.

Season checks that appear on the faces of the stock result both from uneven drying and from the difference between tangential and radial shrinkage. Checks caused by uneven drying may be due to one of two conditions. With excessively rapid surface drying, the outer layers become much drier than those in the interior and tend to shrink before the inside portion is dry enough to do so. The stresses thus set up in the piece may cause checking, which may become apparent either immediately or when the stock is run through the planer. The other condition causing checks obtains when a portion of the piece is shut off from the air. The exposed portion begins to shrink before the protected one is dry enough to do so, and checking occurs in the shrinking portion because of the restraint of the unchanged one. Stickers are often responsible for such checks in the stock. The checking in plain-sawed pieces for which the difference between radial and tangential shrinkage is responsible occurs because the face of the piece that is closer to the heart is more nearly a radial face than the other. Such a piece also tends to cup, but because it may be restrained by the stickers the stresses set up may result in checking. The avoidance of excessively rapid drying tends to reduce all forms of checking, while a decrease in the area covered by the sticker will materially lower the amount of checking resulting from differences in exposure to the air.

Very wide flat-sawed boards and planks are liable to check. For this reason it is advisable to season lumber, particularly aircraft stock, in the narrowest usable widths, unless warping interferes.

HONEYCOMB

The surface of a piece of green wood dries before the interior, and in consequence its shrinkage is opposed by the interior, which during the early stages of drying remains above the fiber-saturation point. During these stages the difference in tendency to shrink sets up a tension in the surface, which may result in checking, and a compression in the interior; the tension and the compression are across the grain. As the drying process continues shrinkage of the interior begins, and in turn is opposed by the surface, which has become set in an expanded condition; that is, the surface has been partially restrained in shrinking and consequently is wider across the grain than it would be at the same moisture content if it had been free to shrink. The difference in shrinkage now results in a compression of the surface and a tension in the interior. The compression may be sufficient to close the surface checks so that they become invisible. (Pl. 1.) Although the checks possibly are invisible and can not be detected by a grader, they may again become visible if the piece is exposed alternately to high and to low humidities either in a dry kiln or elsewhere.[13]

The interior tension just described may exceed the strength of the wood, and consequently may tear the interior fibers apart. If it does so, the resulting defect is called honeycomb. The minimization of honeycomb involves methods of piling that will retard the drying rate.

CASEHARDENING

When the surface of a piece of wood is set in an expanded condition, and consequently is in compression, while the interior is in tension, the piece is said to be casehardened. When such a piece is resawed the new surfaces tend to become concave. If casehardening is objectionable, it can be relieved by proper steaming methods in a dry kiln. For most purposes for which stock in the air-seasoned condition is to be used, however, such a procedure is not required.

CUP, BOW, CROOK, AND TWIST

Cupping, the transverse (crosswise) concaving of a piece of lumber, is caused in a number of ways. The difference in shrinkage resulting from uneven drying is often responsible. When stock is piled with two layers to the course, one face of each piece dries more rapidly and reaches a lower final moisture content than does the other. This condition may result in cupping. Further, a plain-sawed board, although uniformly dried, may tend to cup because, as previously mentioned, the face that grew nearer the center of the tree may be more nearly a radial face than the opposite face. Such a condition produces cupping away from the heart. In general cupping may be held to a minimum by allowing both faces of the stock to dry evenly and by proper stickering.

Bow may be defined as a longitudinal distortion of a board, of such a kind that its face has become convex or concave. Crook is the corresponding edgewise distortion. Twist, on the other hand, makes one or both edges of a board take the form of a helix or of a spiral. Warp involves any kind of distortion; it is the general term that includes cup, bow, crook, and twist. Such types of defect are usually the result of uneven shrinkage caused by a lack of uniformity in the structure of a piece of wood. Spiral, interlocked, or diagonal grain is commonly responsible, although the large longitudinal shrinkage of compression wood is the most frequent cause of crook.

[13] See footnote 1.

(Pl. 2.) Minor distortional defects may result from uneven drying, and those defects caused primarily by the wood structure can be aggravated in this manner. Preventive measures consist chiefly in the use of piling methods that will hold the stock firmly in proper alignment.

LOOSENING OF KNOTS

Knots are loosened during seasoning because of the drying of the cementing resins and gums and because of differences in the shrinkage of the knot and of the surrounding wood. Since the axis of a knot-forming branch is approximately at right angles to that of the tree, a knot in a plain-sawed board shrinks away from the wood lengthwise of the board and also shrinks away, though to a less extent, crosswise of the board. Further, since the shrinkage in the thickness of the board (across its grain) is greater than that of the knot in the same direction (along its own grain), knots are often loosened also when the stock is machined, probably as much because the knot frequently projects beyond the surface of the board as because it is harder than the wood around it. The loosening of knots can not be entirely avoided by any method of seasoning, since a certain type of knot is not directly connected with the wood surrounding it; such knots, which are called "encased," are usually surrounded with bark. Depreciation from knot loosening, however, can be reduced somewhat in air seasoning by measures that prevent excessively rapid drying and extremely low final moisture content. When the knot is firmly intergrown with the surrounding wood it is likely to check rather than to come loose as a unit.

COLLAPSE

During air seasoning a form of defect called collapse sometimes occurs in the heartwood of a few species, such as red gum and swamp oak. Rows of cells collapse like a punctured rubber tire; and if the collapse has been at or near the surface, the surface of the wood then has a washboard appearance; this appearance occurs in boards rather than in planks. Collapse is relatively uncommon in air seasoning.

OTHER IMPORTANT DEFECTS [14]

BLUE STAIN

In the air seasoning of such species as southern and western yellow pine, northern and western white pine, red gum, sugar pine, basswood, and maple, the prevention of blue stain is often the major drying problem. This defect is a discoloration of the sapwood that is due directly to the growth within the wood of threads of the blue-stain fungi. These fungi are minute plants that absorb their nourishment from the wood they inhabit, feeding principally upon the cell contents. As the fungous threads grow, they pass from one cell to another, usually through openings in the cell wall, but occasionally boring through the wood itself. (Figs. 8 and 9.)

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[14] The author wishes to make special acknowledgment to the Office of Forest Pathology, which is maintained by the Bureau of Plant Industry of the U. S. Department of Agriculture in cooperation with the Forest Products Laboratory. The Office of Forest Pathology has contributed very materially to the present knowledge of blue stain and other fungous defects in wood.

Blue stain, in its development, appears first in spots or streaks on the surface of the wood. Later, as the fungus penetrates deeply, the entire sapwood may be discolored. The blue-gray color of the stain appears in the wood only after numeous very small threads of the fungus have reached a certain development within the wood cells. (Pls. 3 and 4.) When these threads, feeding on the contents of the cell and to a slight extent on the cell walls, reach a certain stage of their growth, fruiting bodies—comparable in some ways to the seed pods of a flowering plant—are produced upon the surface of the wood. These fruiting bodies, which appear as tiny black specks upon the blued wood, resemble small black hairs or bristles swollen at the base. (Fig. 10, A.) Minute spores, which are comparable to seeds, are ejected from them. (Fig 10, B.)

These spores, when carried about by the wind or other means, cause new infections by germinating on bright lumber green from the saw or on other favorable places. Although a blue-stain organism may be present in certain logs before the logs are sawed into lumber, the chief source of infection is that just mentioned. Accordingly, yard sanitation and discrimination in the repeated use of stickers are highly important measures in blue-stain prevention.

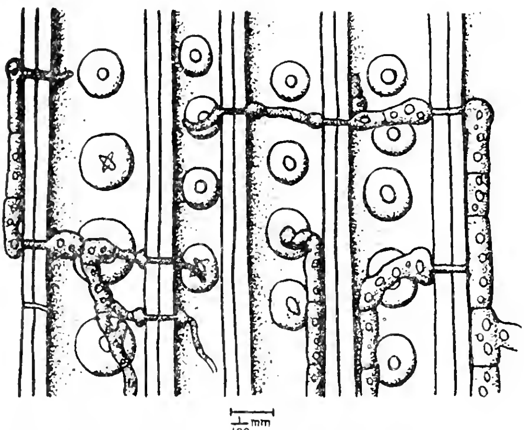

FIGURE 8.—A diagram of young threads (hyphae) of a blue-stain fungus in the cells of a softwood, showing direct penetration of the cell walls. The threads are constricted where they pass through the walls. In the lower center one thread is passing through a bordered pit. Enlarged about 500 times

Blue stain does not materially affect the strength properties of wood; it is not an early stage of decay. The stain, however, often lowers the value of the product for uses, such as natural-finish surfaces, where the discolorations are objectionable.

Blue-stain fungi require an abundant food supply in the wood, a comparatively high moisture content of the wood, and warm weather. Blue stain is likely to occur, especially during rainy periods, in the warmer seasons of the year when the air is humid and seasoning is correspondingly slow, particularly if proper piling and storage methods are not employed.

It has been observed that blue-stain fungi grow best on substances that contain some acid; the acid of sour sap is very favorable for the development of the blue-stain and decay organisms. This fact indicates why souring or fermenting of the sapwood is often advanced as the origin of the blue-stain blemish and decay instead of the true cause, fungous development.

The blue-stain organisms ordinarily do not attack the normal living tree. In wood products the blued areas are usually confined to the sapwood, ending where the heartwood begins. The fact that some species of wood blue more readily than others has not been explained. Possibly the food or moisture conditions in the sap vary sufficiently among species to account for this selective action. From the investigative work conducted so far on the moisture requirements of the blue-stain organisms it seems safe to assume that there is little danger of sap-stain development in wood that has a moisture content not exceeding 20 per cent.

The relation between the seasoning process and blue-stain fungi is obvious. The occurrence of this defect is primarily the result of insanitary yard conditions and of practices conducive to slow seasoning. Measures for minimizing it include steaming, chemical dips, yard sanitation, and yard practices that will permit rapid seasoning, especially in the initial stages of seasoning and in the lower third of the lumber pile. Preliminary steaming and chemical dips are discussed on pages 52 and 53.

BROWN STAIN

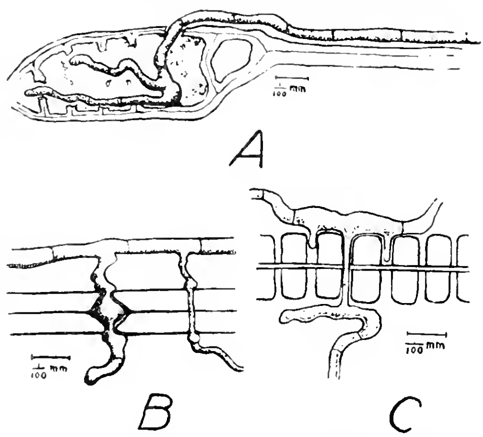

FIGURE 9.—A diagram of a blue-stain fungus in a softwood decomposing the wood ray at A and penetrating the cell walls at B and C. Enlarged about 500 times

Brown stains occur during both air seasoning and kiln drying; consequently they are sometimes called yard brown stain and kiln brown stain. Yard brown stain appears as a yellow to a dark-brown discoloration, chiefly in air-seasoned sapwood and heartwood stock of sugar pine, western yellow pine, and northern white pine. Kiln brown stain is also yellow to dark brown in color: it develops during kiln drying of the heartwood and sapwood stock in the species just mentioned, and also, for example, in hickory sapwood.

The brown stain that occurs during air seasoning, while definitely known in some cases to be due to chemical action, in other cases may be due to fungous action. Kiln brown stain is of a chemical nature. The cause of chemical brown stain is not definitely known, but it is thought to be due to the deposition and subsequent oxidation of water-soluble materials as the wood dries. Sometimes the chemical stain appears on the surface of a rough board. Frequently, however, the water-soluble substances appear to be concentrated just beneath the surface, and the stain does not become evident until the board is planed.

No positive remedy for brown staining is yet known.

DECAY

What has been said with reference to the cause of blue stain and the conditions conducive to its growth is applicable likewise to wood-destroying fungi, with one important exception, namely, blue-stain fungi affect the strength to only a minor degree if at all, whereas the wood-destroying organisms use certain constituents of the cell walls of the wood for food, with the result that the cells may be broken down and the strength of the wood may be greatly reduced.

INSECT ATTACK [15]

Certain woods are subject to insect attack in the green lumber, some in insufficiently seasoned lumber, and others in dry lumber. Some of the wood-destroying insects bore into sapwood and heartwood without discrimination, whereas others confine their eating to sapwood or even to bark. The sapwood of a few fully seasoned hardwoods is attacked by an insect known as the powder-post beetle. This beetle lays its eggs in the pores of the wood, and the eggs are big enough to require large pores. Hence hickory, ash, and oak are most liable to its injury, but other species are also attacked to some extent by this same beetle. The actual destruction of the wood comes from the larvæ of this borer, as is usual with such insects. With some wood destroyers, however, either the adults alone or both the adults and the young do the damage.

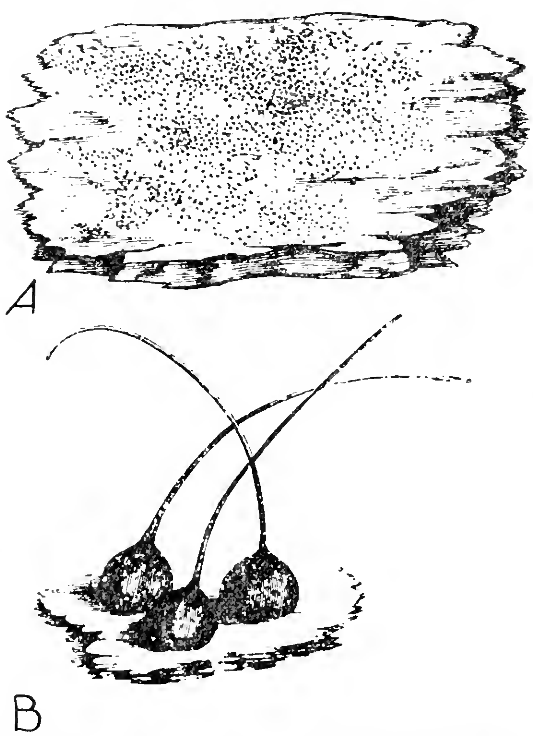

FIGURE 10.—A, Fruiting bodies of blue stain (*Ceratostomella* sp.) appearing as black, powdery masses on a portion of a board; B, fruiting bodies, enlarged about 70 times

On account of borer attack, seasoned hickory, ash, and oak in storage should be moved in rotation, old stock being used before new, so that none of it will remain in storage an excessively long time. In addition all stored stock should be examined regularly and with care. Any stock showing the slightest indication of attack should be reexamined, often by cutting into it, and borer-infested stock should either be heat sterilized or destroyed. The powder-post beetle lays its eggs below the surface of the wood, usually entering the piece from the end, and the larvæ ordinarily work in-

[15] The author is pleased to acknowledge the assistance of the Bureau of Entomology, U. S. Department of Agriculture, in the preparation of this section.

ward, so that a piece of wood may be eaten to a shell before any external indications of the destruction appear. Further, the adult beetles fly, which makes infestation of adjacent stock merely a matter of time if proper preventive measures are not taken.

Without much question, economic considerations justify both constant inspection of stores of the woods most subject to borer attack and also suitable heat sterilization of such stock immediately before its remanufacture. Similar treatment is desirable for all seasoned wood subject to the attack of any insect.

Seasoned stock that is entirely free from the eggs and larvæ of powder-post beetles may be protected from attack through filling the pores of the wood with varnish or gloss oil, which will prevent the adult beetle from laying its eggs in the wood.

KILN DRYING TO KILL WOOD BORERS

About 180° F. is required to kill many of the borers that infest wood, although considerably lower temperatures will suffice for some. When wood infested by heat-endurant borers, such as the Lyctus powder-post beetle, has not been subjected to a temperature of 180° or higher during the drying process, the kiln temperature should be raised to 180° at the end of the run and so held for a half hour or longer, the exact time depending upon the thickness of the stock. If the moisture content of the wood does not exceed 12 per cent, and if the relative humidity during the heating period is controlled so as to prevent any visible damage, it is improbable that subjecting the stock to 180° for two or three hours will injure the strength of the wood.

KILN DRYING PRELIMINARY TO AIR SEASONING

Subjecting green lumber to relatively high temperatures accomplishes more than merely killing the fungi and insects present. When such temperatures are employed in conjunction with proper relative humidities, as in kiln drying, the process offers also a means of minimizing checking in refractory hardwood boards during subsequent air drying. The principle involved may be understood by referring to the discussion of honeycomb on page 25 and by the following considerations: During the early stages of kiln drying, the rate of drying, under proper conditions, can be controlled so as to prevent checking. At some point in the drying process the stress in the surface of the board changes from tension to compression. At this point, which in northern red or white oak, for instance, may be at a moisture content of about 30 per cent, the danger of checking is practically gone, as long as the surface does not subsequently absorb moisture and then again lose it. Consequently the problem of minimizing checking in refractory hardwoods may be simplified by preliminary kiln drying for several days before the stock is piled in the yard. To make it possible for such drying to remain effective, however, care must be taken to protect the stock from rain.

COMMERCIAL METHODS OF PILING BOARDS, PLANKS, AND OTHER SHAPES OF WOOD FOR AIR SEASONING

BOARDS AND PLANKS

FLAT PILING

Yard Site

While in some cases the location of the seasoning yard is limited by such factors as availability of the timber supply and means of transportation, when possible the site selected should be well drained, and for species that withstand rapid drying should be on high ground well exposed to the wind. Freedom from débris, weeds, and other vegetation is essential if the development of blue stain and decay is to be kept at a minmum.

Obviously the opportunity for movement of air around the piles shown in Plate 5, A, is much greater than for those in Plate 5, B.

Yard Layout

MAIN ALLEYS

To facilitate the transportation and piling of lumber the main alleys should be 16 to 20 feet wide. (Pl. 5, A.) In some yards the alleys have no surfacing, in others planking is used, and occasionally alleys are surfaced with concrete.

REAR ALLEYS

In some instances the rear alleys are used for unpiling the lumber. Even though they may not be used for this purpose, they should be at least 8 feet wide if rapid air movement is needed. The advantage of the alleys shown in Plate 6, B and C, as compared with that in Plate 6, A, is evident.

CROSS ALLEYS

The alleys at right angles to the main alleys should be spaced 200 or 300 feet apart to facilitate the movement of lumber. If they are made wide enough, say 60 feet or more, they will tend to limit the extent of a fire. These alleys, like the others, of course influence the movement of air through the yard.

TRAMWAYS

Because of variations in the level of a yard and also in order to permit higher piling without mechanical equipment, elevated wood runways, called tramways, are sometimes built in the main alleys. (Pl. 7, A.) It has been found, however, that a tramway in front of a pile materially retards the drying rate in the lower part of the pile and increases the danger of depreciation from blue stain and decay to such an extent that the apparent advantages ordinarily are outweighed by the disadvantages.

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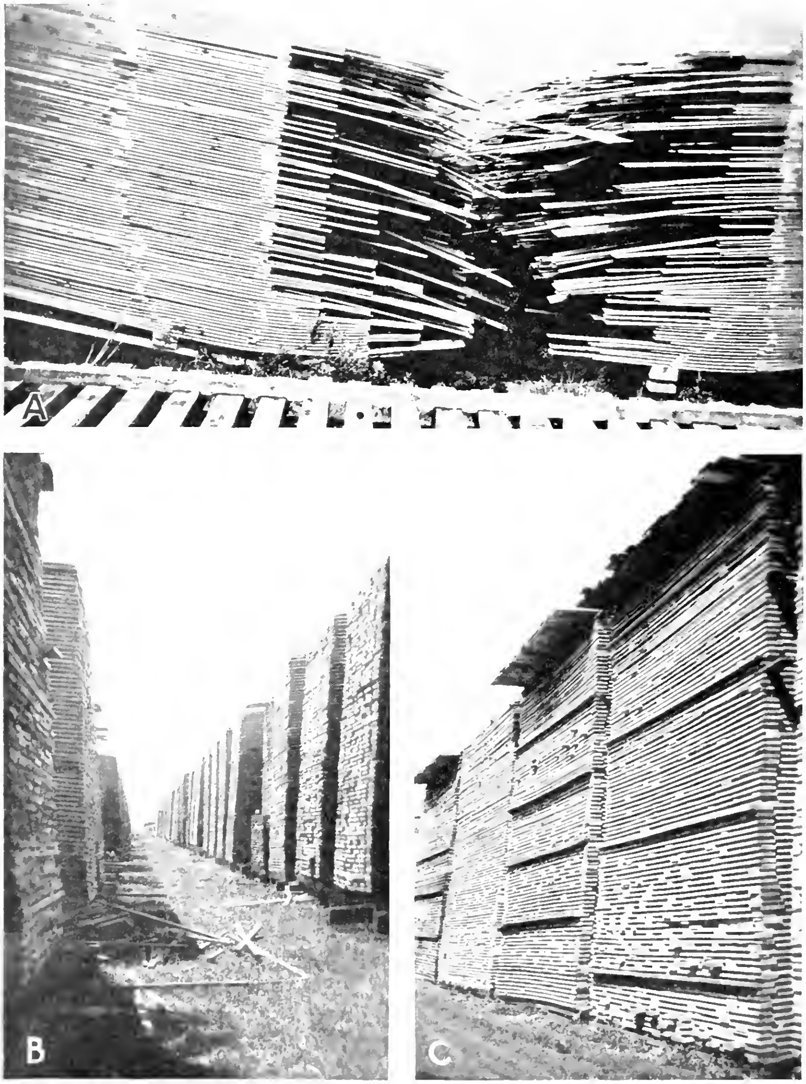
Sanitation in air-seasoning yards: A, Excellent sanitation in an air-seasoning yard; the layout, the foundations, and in the main the piling also are good. All these features are conducive to the necessary good ventilation in the piles; B, poor sanitation in an air-seasoning yard. The loss resulting from stain and decay that are directly chargeable to the choking of circulation caused by the weeds alone would more than pay the cost of putting the yard into good condition and maintaining it properly



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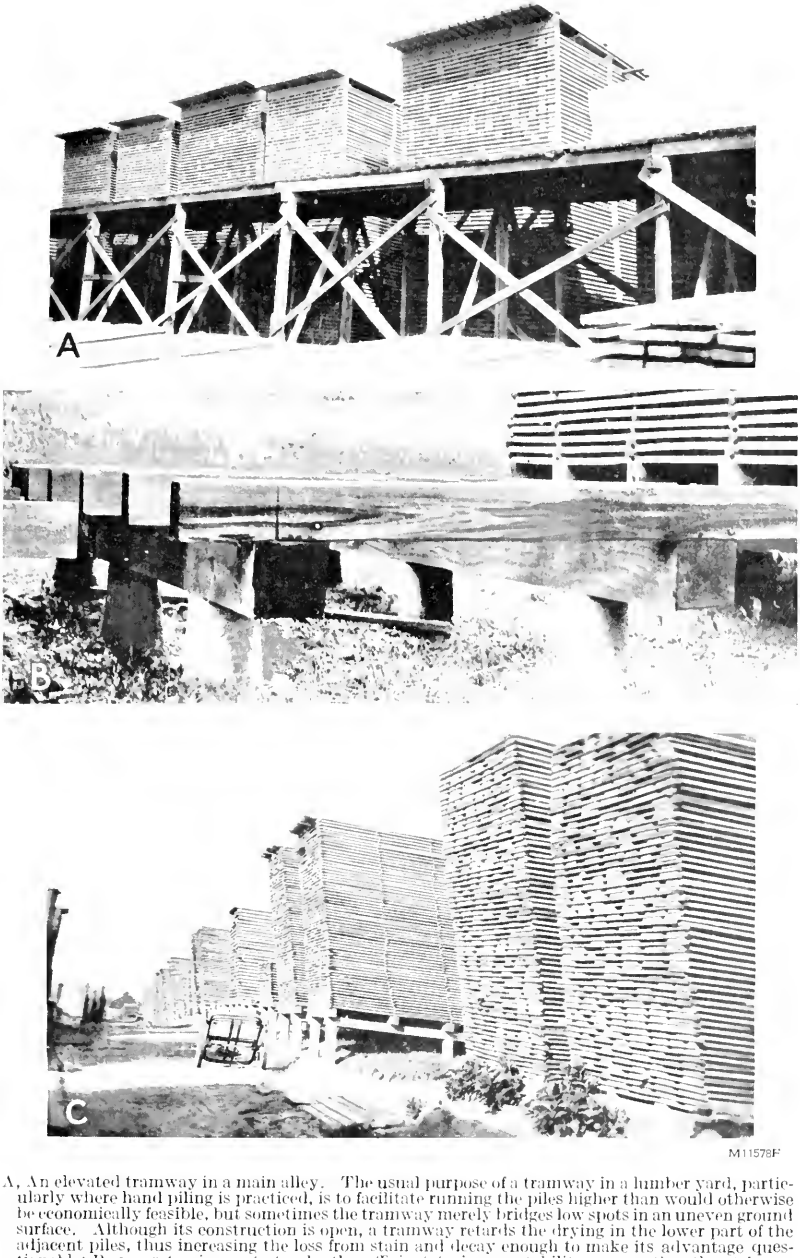
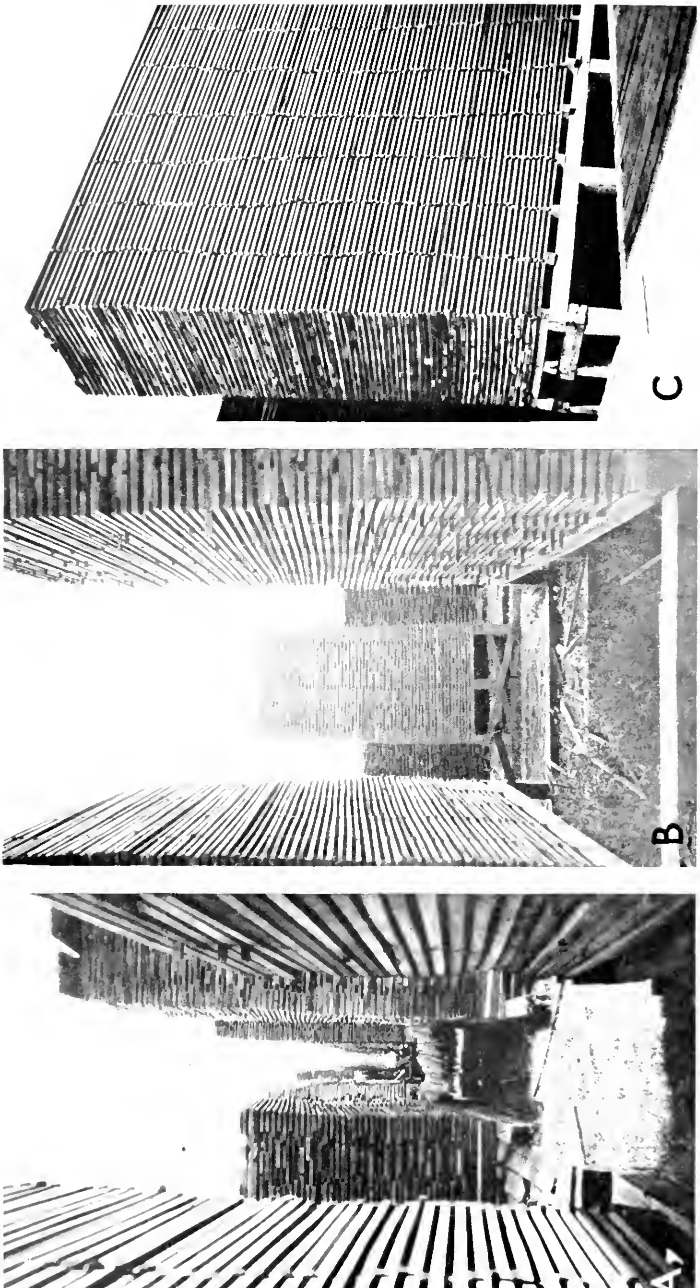
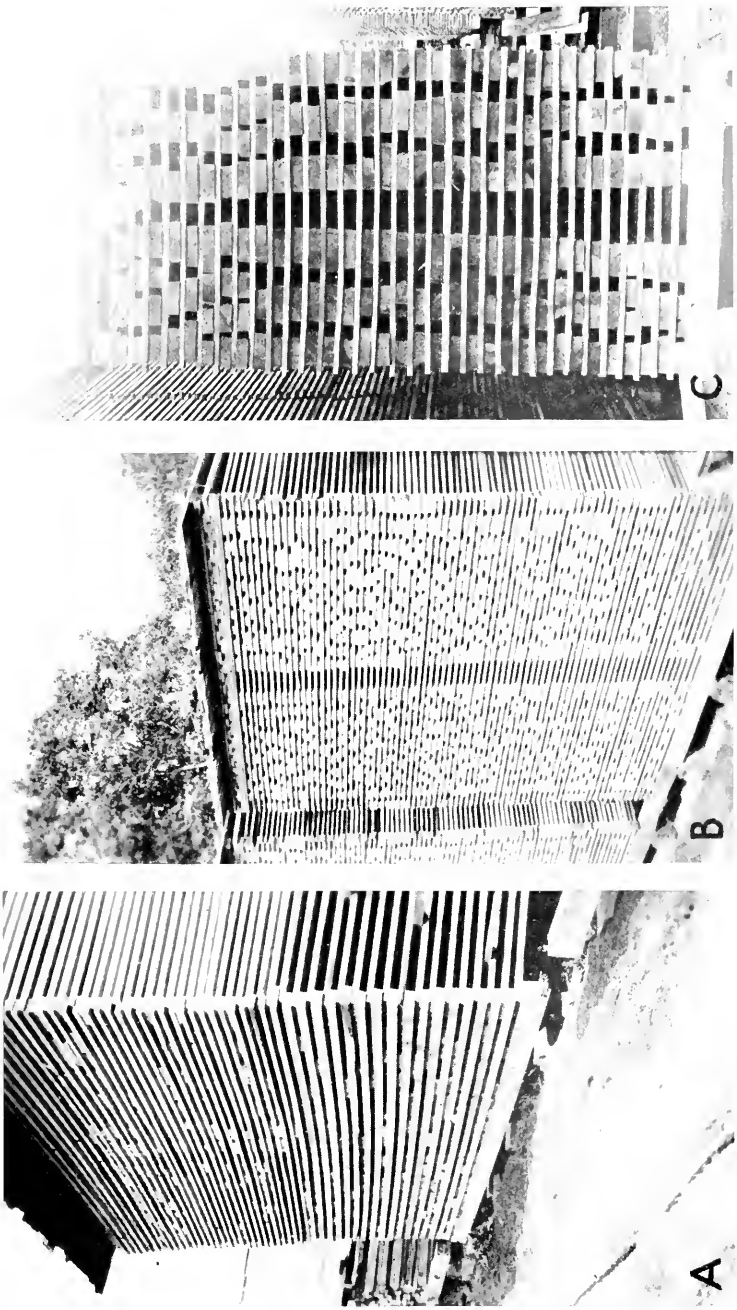
Rear alleys; bad and good practice: A, Poor piling of yard lumber. Overhanging ends, inadequate stickering, insufficient and improper foundations, weeds, and a narrow and obstructed alley all cause degrade, with its resulting loss; B, an adequate rear alley, wide and well-kept except for the few scattered stickers. All the piles are set up properly (box piled), and the sanitation is good; C, one side of a well-appearing rear alley. The stock is piled without overhanging ends (box piling), a desirable feature. Three or four rear pile ends, in addition, have drip boards. On the other hand, higher foundations are desirable



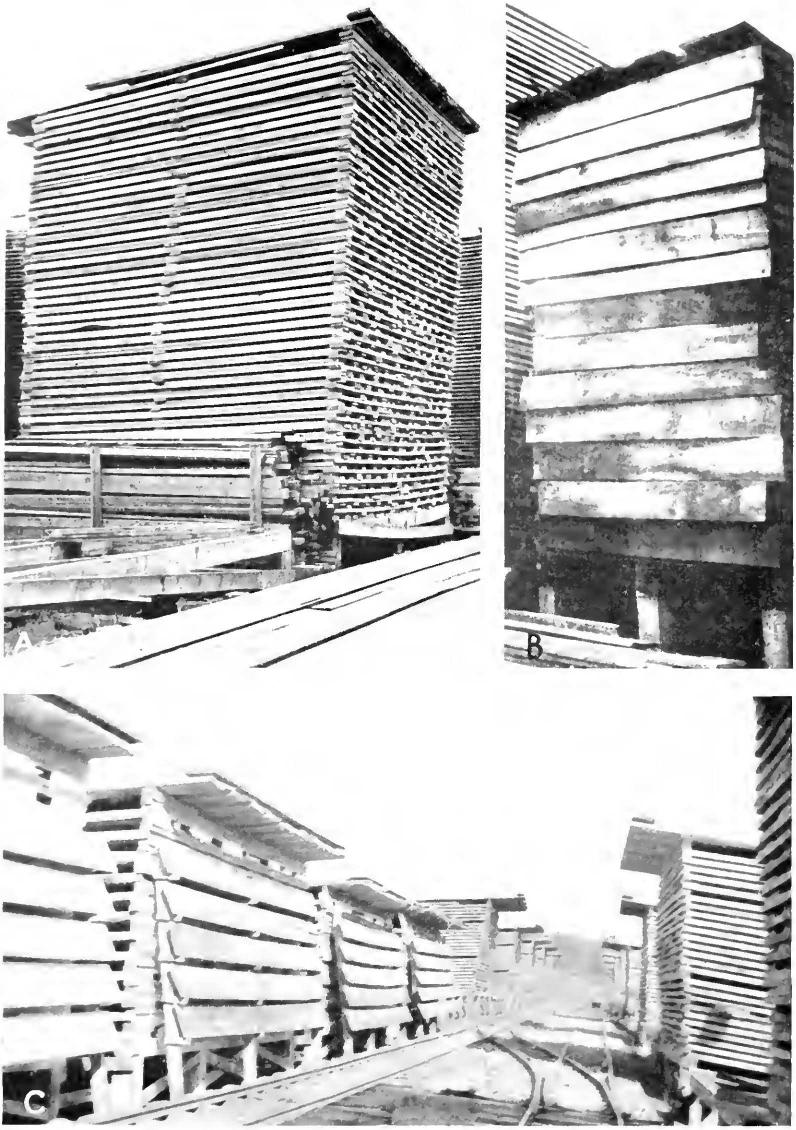
A, An elevated tramway in a main alley. The usual purpose of a tramway in a lumber yard, particularly where hand piling is practiced, is to facilitate running the piles higher than would otherwise be economically feasible, but sometimes the tramway merely bridges low spots in an uneven ground surface. Although its construction is open, a tramway retards the drying in the lower part of the adjacent piles, thus increasing the loss from stain and decay enough to make its advantage questionable; B, concrete piers, set at a depth sufficient to insure stability, supporting the stringers and beams of a pile foundation; C, concrete piers adequate in height and well-kept surroundings, as shown in the center of the illustration, make for excellent ventilation and tend to prevent loss from stain and decay. The low and solid foundations, at the right, are in marked contrast



Yard piling practice: A, The alley between lumber piles that are in excellent lateral alignment; B, a section of the alley formed by staggered lumber piles; C, each tier of stickers in the pile is firmly supported by a beam, which in turn rests solidly on a stringer



Methods of piling to increase circulation: A, A lumber pile with its lower third opened up by means of stickers thicker than those in the rest of the pile; B, a central chimney of uniform width in a yard pile of random-width lumber; C, a tapered central chimney in a yard pile



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A, A roof of standard-length lumber made in two sections, one overlapping the other, to permit adequate extension of the roof at both the front and the rear of the yard pile. The practice of double decking; that is, piling two layers of boards between two consecutive rows of stickers as also shown in the illustration, is liable to cause an excessive amount of checking and warping; B, a yard pile boarded up to shield the lumber from the direct rays of the sun, thus reducing the excessive end checking that is caused by too rapid drying; C, a simple and effective type of portable sun shield for protecting the ends of the lumber from the direct rays of the sun

Foundations

REQUIREMENTS

The principal requirements of satisfactory supports for a lumber pile are firmness, durability, and a height sufficient to allow the air that has circulated through the lumber to escape readily, especially by allowing wind from any direction to blow beneath the pile. The minimum distance between the ground and the first layer of lumber should be 18 inches. Firmness and durability are required to prevent sagging and consequent warping of the stock.

UNIT FOUNDATIONS

Foundations may consist of heavy planks resting directly on the ground and supporting piers and stringers. The unit type, as this construction is called, is built the same width as the pile and separate from the adjoining foundations. Such a foundation permits definite alignment of the piles (p. 36), is readily adjusted for different lengths of stock, and is easily repaired. A disadvantage is the tendency of the wood in contact with the ground to decay.

CONTINUOUS FOUNDATIONS

The stringers of the continuous type of foundation are supported in a manner similar to that of the unit type, but they extend from one cross alley to the next.

PIERS

Concrete piers, which are sometimes built as shown in Plate 7, B, are very satisfactory. The low, solid foundations shown at the right in Plate 7, C, are in marked contrast with those near the middle of the illustration; the solid ones should not be used because they prevent proper circulation under the piles.

SLOPE

Regardless of the type of foundation, the slope from front to rear should be approximately 1 inch to the foot of length of pile.

PRESERVATIVE TREATMENT

Timbers used in the construction of foundations for lumber piles should be impregnated with creosote, especially if they are of a nondurable species of wood or the sapwood of any species. If the cost of the impregnation process is not justified, the timbers should at least be given two coats of hot creosote, or an equivalent treatment, on the surfaces that are to be in contact with other surfaces or with the ground. I-beams and inverted railroad rails also make satisfactory stringers for such service.

SEPARATION OF STOCK

Because of the marked difference in the drying rates and in the seasoning degrades of stock of various species, grades, and thicknesses, the separation of stock should in some cases be made at least on the basis of these three factors. For instance, 4/4-inch sap gum requires rapid drying conditions to prevent blue stain, while 4/4-inch southern lowland red or white oak should be subjected to more moderate drying conditions, since it is very liable to check and to honeycomb. Upper-grade stock of coniferous species is clear, while the lower-grade stock has knots, which are liable to check and become loosened if subjected to the extreme drying conditions that the upper grades can withstand. Likewise the conditions to which the heartwood of red gum should be subjected are more mild than those proper for its sapwood. Thus in any species in which the drying rates of heartwood and of sapwood differ materially, separation on this basis should be given careful consideration.

Thick stock of a given species requires a longer drying period than thin stock does and is also more liable to check. Further difficulty is encountered when pieces of more than one thickness are piled in the same layer, since the stickers then fail to hold the thinner pieces in position effectively and therefore permit warping. In addition, such thin pieces in a layer fail to support the stickers above them, a condition that always causes at least deformation of the unsupported stickers, with resultant injury to the stock above them, and may cause breakage of the stickers, with still greater injury to the stock.

Not only is it advisable to separate the stock with respect to species, grades (at least by groups), and thicknesses, but proper piling will be facilitated and seasoning degrade will be reduced if the separation is made also with respect to width and length. With uniform-width stock, straight flues of any desired width from bottom to top can be provided so that air movement will be reasonably uniform throughout the pile. When the lumber is separated as to length, piling so as to avoid overhanging ends, which are liable to check and warp, is simplified.

For hardwoods, the distance between flues should ordinarily be about 12 or 14 inches; too great a distance causes too slow drying. Boards, including those of random width, may be grouped to obtain the proper distance; for example, three 4-inch boards, two 6-inch, or one 4-inch and one 8-inch are all equivalent to one 12-inch board.

For much softwood lumber the distance between flues should be approximately the same as for hardwoods. Local conditions, however, always determine the exact spacing that is proper; the species of lumber is merely one of these conditions. Extremely high humidity and light winds, for instance, might make correct a spacing between flues of only 8 inches, and on the other hand when the boards are 30 inches wide the flue spacing obviously can not be less than 30 inches.

TYPES OF PILES

RANDOM-LENGTH PILES

Sometimes the separation of stock with respect to length is not feasible. Too often the result of piling random-length stock without sorting is as shown in Plate 6, A. Except for very low-grade material, such a method of piling should never be used, since the consequent depreciation in the value of the stock because of warping and checking is unnecessarily high; the loss in such depreciation will more than equal the additional cost of proper piling.

BOX PILES

If stock is piled without overhanging ends, as the lumber in Plate 6, B and C, is, the method is called box piling. In piling random-length stock for air seasoning, the longest boards or planks should be placed in the two outer tiers; and if there is a sufficient number of these boards for additional tiers, such tiers should be uniformly distributed across the width of the pile. As far as possible the boards throughout any tier should be of the same length, whatever that length may be. Whether the short boards should all be placed with their ends flush with the front face of the pile or whether adjacent short-board tiers should be flush with the front and the rear faces, respectively, depends on the stickering. Let us suppose, for example, that 12-foot and 16-foot boards are being piled and that three tiers of stickers are adequate for the 16-foot stock. If the short-length tiers of boards are all flush with the front face of the pile, one less tier of stickers to support the ends of the 12-foot stock will be required than if the alternate method is used. On the other hand, if the number of interior 16-foot tiers is limited, saving one tier of stickers by such piling may result in too much sag in the rear tier of stickers, which is almost certain to deform the boards resting on them. If five or more sticker tiers are required to keep the 16-foot stock from warping, adjacent short-length tiers of boards should be placed flush with the front and the rear faces of the pile, respectively. Such staggering of the short-length tiers is well adapted to a pile in which there are no interior long-length tiers of boards.

Minor modifications of the method of piling just described are also called box piling. For example, in proper kiln drying, with flat piling, the tiers of long boards are grouped in the sides of the pile instead of being distributed over it, and the tiers of short boards are always staggered from end to end instead of sometimes being concentrated at one end. This distribution of the vertical air channels at the ends of the short tiers is required for proper circulation in the limited space within a dry kiln. Again, in air-seasoning practice the term "box piling" is sometimes applied to properly piled boards of the same length, either nominal or actual. The essential features of the box pile are accurate separation of the boards by length, the use of long boards for the outer tiers, and proper support under each end of every board, so that no ends overhang.

SPECIAL PILES

One intentional divergence from an essential feature of the box pile is sometimes found in the piling of certain self-stickered softwoods, especially with wide boards. The rear stickers are set back 18 to 24 inches from the ends of the stock, perhaps with the idea that, when the boards are not trimmed accurately to length, it is impossible to have the stickers flush with their ends. When it is possible, however, placing the rear stickers so that they overhang the ends at least 1 inch is desirable, because then less end checking is likely to occur.

Another divergence is the staggering of the middle and the rear tiers of stickers. This practice appears advantageous for the middle tier; it should decrease both the moisture content and the checking of the portions of the boards and stickers that are in direct contact. At the same time, if the staggering is not properly done, there is danger of warping. In such staggering one edge of each sticker is directly over the center line of the sticker below it, and successive stickers are offset in opposite directions.

Direction of Piling

Almost invariably boards and planks are piled perpendicular to the main alley, as in the piles previously illustrated. This method is endwise piling. Occasionally, however, the lumber is piled parallel to the alley; this practice is sidewise piling. The sidewise method might be expected to afford more rapid drying than the endwise because the face of the sidewise pile, next to the alley, is more open than that of the endwise pile. The conclusion from examination of actual air-seasoning test piles in the southern yellow pine region, however, was that the difference in drying rate between endwise and sidewise piling was negligible. It appeared also that the difference in the amount of blue stain resulting from the two methods was negligible, although the data on this point were not sufficient to be conclusive. Sidewise piling is more inconvenient than endwise piling and is probably more costly.

Pile Spacings

In the various lumber regions the lateral spacing between yard piles varies from a few inches to 6 feet. This spacing is one of the most important factors affecting the air movement around and through the piles. It is hardly possible to recommend the proper lateral spacing in all cases. Broadly, and by way of example, it may be stated that 4 feet for species such as the pines and that 6 feet for the sapwood of red gum and for basswood are considered satisfactory. A definite answer in a given case depends upon how rapidly the lumber dries, the width of the pile, the lateral and also the vertical spacing between adjoining boards, whether checking or stain is likely to be the principal cause of degrade, and climate.

Irrespective of the lateral spacing it is advantageous from the standpoint of the effect on general air movement through the yard to have the piles aligned as shown in Plate 8, A. An alternative arrangement sometimes used is a "checkerboard" layout as illustrated in Plate 8, B. In this plan the piles on one side of an alley are directly opposite spaces of the same width on the other side. In other words, only half the usual number of piles is placed on each side of the alley. Although the checkerboard arrangement undoubtedly has advantages, the superiority of the checkerboard over the more usual layout, when the usual layout is given the same proportion of free space, has not yet been proved.

Occasionally the piles are so disposed in a yard that there is some opportunity for selecting the foundations on which fresh stock is to be put. If a species like sap gum is to be seasoned, the piles should be placed as far from other piles as possible in order to hasten the drying rate. On the other hand, if oak is to be seasoned, the stock should, if possible, be placed between two piles of some other green stock to retard the drying rate and thus reduce checking and honeycombing.

Pile Widths

The width of a pile affects the rate of drying, and should therefore be given careful consideration before any particular dimension is adopted as permanent.

In the softwood regions the width of a pile is usually made equal to its length. In the South the width of hardwood piles is generally 6 feet, while in the North it is 12 to 16 feet. For sapwood boards of a species like red gum a very narrow pile is desirable, in order to hasten drying and to decrease blue stain. With oak, on the other hand, the danger of checking and honeycombing is very great, and from this standpoint extremely narrow piles are objectionable. At the same time wide piles do not fit in well with a southern hardwood operation because of the large number of items and the relatively small amount of each item cut daily at the average southern mill. Consequently the wider the pile the more the stock is exposed to sun and rain before the roof is provided, because the pile then is built up more slowly. Possibly it would be worth while for hardwood operators, especially in the South, to consider devising a form of roof built in sections of convenient size and weight that could be placed over incompleted piles until additional stock is available.

The marked effect of the width of the pile on the drying rate was indicated by two piles of redwood, 8 and 16 feet wide, respectively, that were of the same class of stock and erected at the same time. In 136 days the narrow pile reached a moisture content of 19 per cent. while the other pile dried only to 36 per cent. Although redwood, the species selected for this drying test, is not subject to blue stain, it is reasonable to expect that the faster drying rate obtained with the narrow pile would reduce blue-stain loss in species that are subject to such attack. Narrowing the pile unquestionably has somewhat the same result as opening up the pile, a matter that is discussed a little later under the headings "Stickers" and "Board spacings."

Pile Height, Pitch, and Slope

In the western softwood regions the height of piles averages probably 14 to 18 feet and in the southern softwood regions about 12 to 16 feet, except in yards with tramways or with mechanical piling equipment, where the height may be 20 feet or more. In the southern hardwood region the height averages about 12 feet and in the northern hardwood region about 15 to 18 feet, although in northern yards having tramways the height is sometimes 30 feet. Since the general trend of the air movement in a pile is downward, it is obvious that the higher the pile the greater will be the difference in drying rate between the top and the bottom of the pile. No significant difference has been found in a pile 10 feet high, but in a 20-foot pile the difference is considerable. Thus the advantage of saving yard space by the use of high piles may be offset by retardation in the drying rate and resultant degrade in the lower part of such a pile.

The usual pitch of the front face of a pile toward the alley is about 1 inch to the foot of height. Such inclination permits the rain to drip from the front face, so that the water is less likely to trickle through the pile. The slope of the pile from front to rear is usually about 1 inch to the foot of length, an amount that permits water entering the pile from the top or the sides to drain off.

Stickers

The strips or boards used for separating the layers in a pile are generally referred to as stickers, and sometimes as crossers. They are of two kinds: Stock stickers and special stickers. As the name indicates, stock stickers are boards of the same kind as those being piled. Special stickers, on the other hand, may be of the same or of a different species. The usual special sticker for softwoods is nominally 1 inch thick by 4 inches wide, and for hardwoods is nominally 1 inch thick by 1¼ inches wide. All stickers in the same layer should be of uniform thickness to minimize warping.

Where the prevention of checking or staining is important, special stickers should unquestionably be used. With low-grade stock, however, the use of stock stickers is justified, not only because the loss from depreciation is small but also because they permit more stock to be piled both in a given space and in less time than when special stickers are used.

Special stickers should at least be thoroughly air-dry if not kiln-dry in order to minimize blue stain, decay, and checking in the lumber they support. If green stickers are used the portions of the boards in contact with them dry out more slowly than do the remaining portions, thus increasing the danger of fungus development and at the same time setting up shrinkage stresses that may result in checking. Heartwood is preferable to sapwood for stickers because it does not blue stain and is more resistant to decay.

The number and the position of stickers may have an important bearing on degrade, and these factors, therefore, may vary with the species of the wood to be air-dried. For instance, a sufficient number of stickers is necessary to prevent warping, but too many sticker tiers may result in blue stain and consequently an unnecessary depreciation. Usually three tiers of stickers are considered sufficient for 16-foot western yellow pine boards, while nine tiers are required for red gum boards of the same length. It has been found that if special stickers are placed so that their outer sides project beyond the ends of a pile of boards the drying rate of the wood covered by the stickers is retarded sufficiently to effect a material reduction in end checking; such stickers may be 2 inches wide instead of the customary 1¼ inches. As a rule the stickers should be aligned so that the tiers are parallel to the front face of the pile, in order to minimize warping. Each tier of stickers should be supported directly by a foundation beam. (Pl. 8, C.)

Because of the common tendency of the lower part of a pile to dry more slowly and to stain more than the upper part and because this tendency is directly related to the air movement within the pile, studies have been made of the effect on drying conditions of using thicker stickers in the lower third or half of the pile. (Pl. 9, A.) The results obtained show a very definite advantage for opening up part of the pile by this means. On the other hand, if the thicker stickers were used in the upper part of the pile also, the more rapid drying resulting in that portion would in some instances be objectionable because of increased shrinkage defects.

Where the operator does not wish to carry two sizes of stickers, the desired opening of the pile may be attained simply by doubling the stickers, that is, by using two 1-inch stickers, one on top of the other, instead of one 2-inch sticker. Further increase in the area of horizontal openings to aid circulation within the pile may be provided, of course, by using still thicker stickers, either solid or built up.

Board Spacings—Flues and Chimneys

Mention has been made of the fact that in the main the air movement in a pile of seasoning lumber is downward. Consequently if the stock is separated as to width (p. 34), it can be piled with straight flues, which will aid circulation. The width of flue, which is the horizontal spacing between boards, can be varied to suit the conditions; that is, if the principal cause of degrade is stain, the spacing between boards should be increased. On the other hand, if checking is the principal defect, the spacing between boards should be decreased. The disadvantage of this method is that it can be applied practically only to the entire pile.

More or less arbitrarily, the space between two tiers of boards may be called a flue when it is less than 6 inches in width. If the space is 6 inches or more in width, it may be called a chimney or a vent; it then may be either straight or tapered. (Pl. 9, B and C.)

If ordinary random-width stock is to be piled, it is good practice to provide three or more straight chimneys about 6 inches wide and to place the boards in any layer between two chimneys so that adjacent edges are in contact or nearly so. In this way the edges of the boards on each side of a chimney can be placed in approximately vertical alignment.

If very wide random-width stock is to be piled, it may be more practicable to provide one wide, tapered, central chimney than several narrow chimneys.

Where desirable, it is possible, of course, to supplement the effect of the chimneys by providing increased horizontal openings in the lower part of the pile, as previously described.

Roofs, Drip Boards, and Sheds

Except for very low-grade stock, some form of pile covering is advantageous in decreasing depreciation from alternate exposure to sun and rain, which causes checking and warping. Roofs should always be made of low-grade material, in order to minimize costs. The boards in the first layer of the roof may be spaced about one-half inch apart, and those in the top layer should then be placed directly over the spaces between the boards in the lower layer. The roof, if it is tight, should slope about 1 inch to the foot; if it is not tight the slope must be somewhat greater, perhaps 25 per cent greater, in order to provide for satisfactory run-off. The roof should project about 1 foot at the front and 2½ feet at the rear to aid in keeping snow and rain from the ends of the pile. To afford additional protection, drip boards are sometimes used, as shown in Plate 6, C. Where it is desired to have the roof project in the manner described without using extra-length stock, the sectional construction shown in Plate 10, A, can be provided. However, more space than that shown between the roof and the top layer at the rear would be advisable. In any event this space should be ample to allow plenty of air to enter the top of the pile. An average of 5 inches is considered sufficient for this purpose.

In a windy location the roof should be fastened to the pile by wiring or equivalent means.

End Protection

PROJECTING STICKERS AND SUN SHIELDS

Reference has been made to the fact that if special stickers are placed so that they project beyond the ends of the boards in the layer below them, they will retard the drying rate in those ends and thus decrease end-checking. In thick stock the protection afforded by projecting stickers may be very inadequate, and in this event sun shields may be useful. Plate 10, B, illustrates the use of boards for sun protection, and a convenient type of portable sun shield is shown at the left in Plate 10, C.

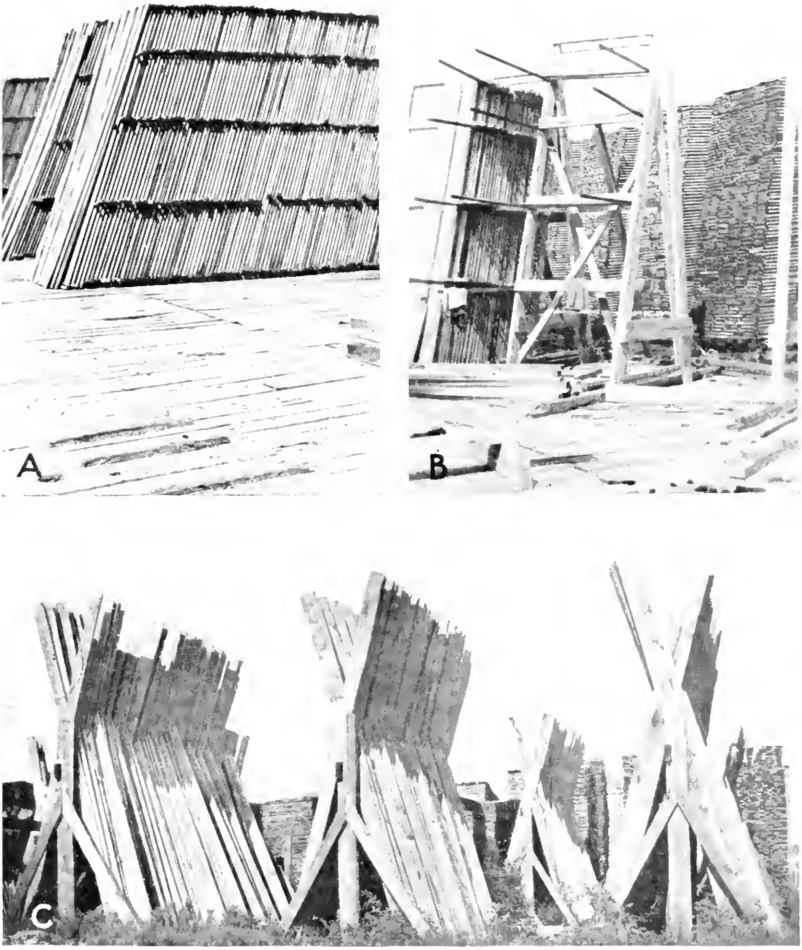
COATINGS

Coatings for reducing changes in the moisture content of wood are another means of protection against end checking. Such coatings should be applied before checking begins. Paraffine is one material that may be used for this purpose. It should be melted so that the stock can be end-dipped in it and thus given a coating about one thirty-second of an inch thick. Another coating material, which may be applied with a brush and which is more convenient to use, since it need not be heated, is filled hardened gloss oil. It is made up by paint manufacturers. Various kinds of hardened gloss oil are on the market, some of which are not suitable for end coatings. Hardened gloss oil having a high degree of resistance to the passage of moisture consists of 100 parts, by weight, of rosin, 8 parts of quicklime, and 57.5 parts of a thinner, such as mineral spirits. Filled hardened gloss oil [16] is made by mixing 25 parts, by weight, of fibrous talc, 25 parts of barytes, and 100 parts of hardened gloss oil; the purpose of the inert pigment is to increase the moisture resistance.

END PILING

End piling for seasoning, which is illustrated in Plate 11, is used to a limited extent in piling sap gum in the drier sections of the southern hardwood region. Thick, clear lumber in the sugar-pine

[16] A list of the dealers from whom the component materials may be purchased can be obtained, upon application, from the Forest Products Laboratory.



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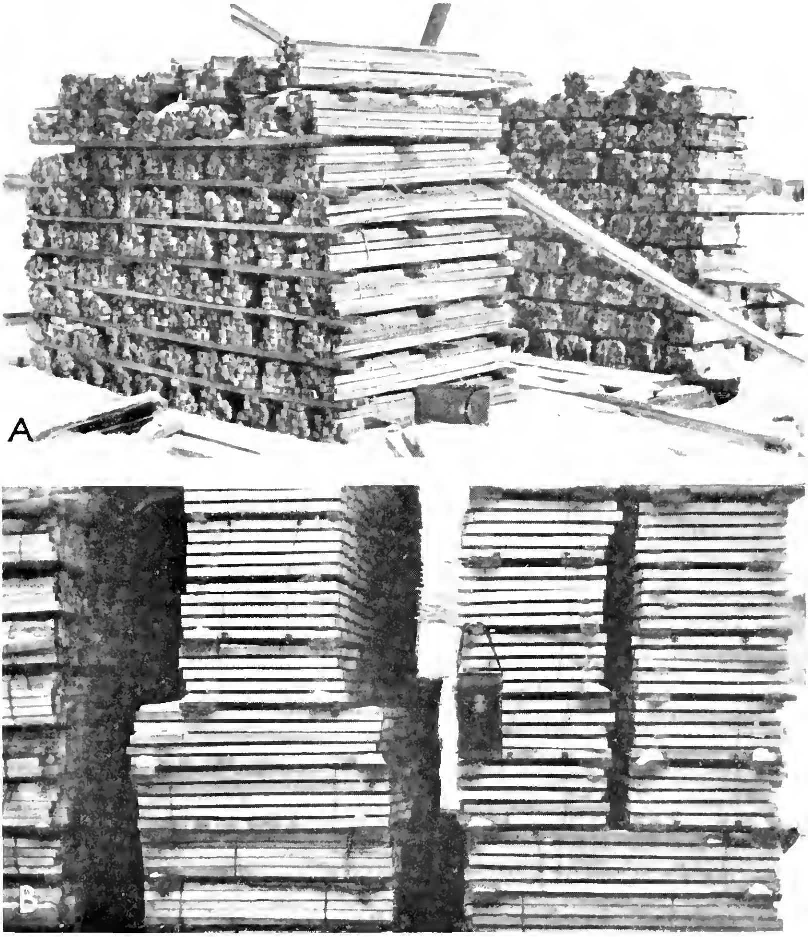
Some methods of piling other than flat: A, Lumber end piled on a solid wooden platform. An open foundation for each pile, raised a foot or more above the ground, would afford better air movement around the bottom of the pile; B, a rack for the end piling of lumber; C, yard lumber end racked in the form of an X

Reasonably good end-racking practice: A, Yard lumber end racked in the form of an inverted V; B, supports for end racking lumber



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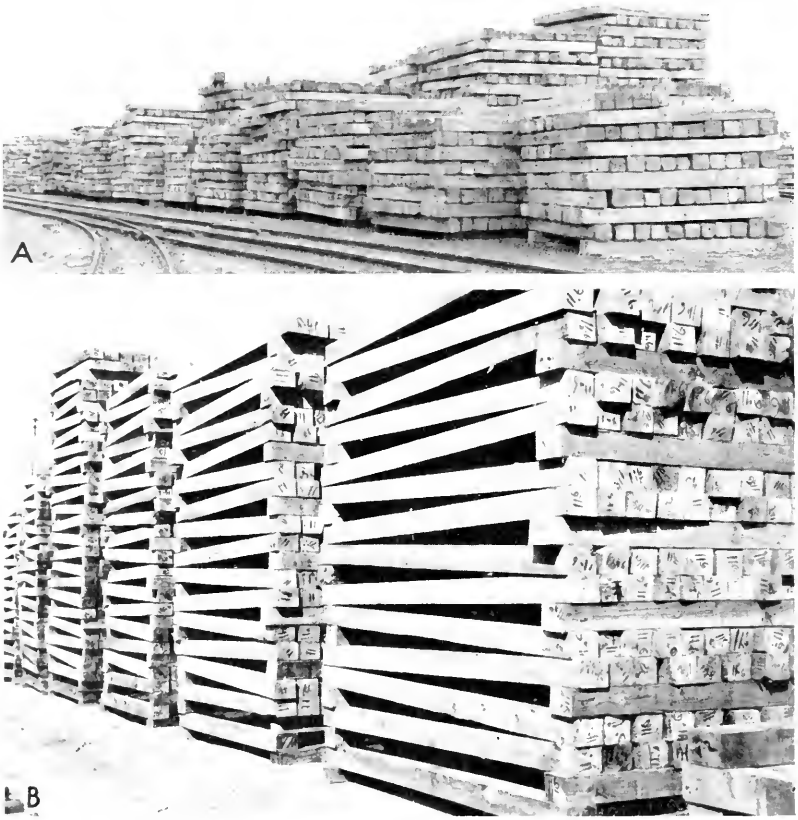
Piling of bundled dimension stock: A, Twine-bound bundles of dimension stock piled in the open; B, wire-bound and twine-bound bundles of dimension stock having stickers between courses, and also twine-bound solid bundles, all with stickers separating layers of bundles



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Railway crossties piled for air seasoning: A, Solid piling with 11 by 11 layers; B, a common form of open piling; the illustration shows 10 by 1 layers region of California is also occasionally end piled under shelter. End-piled lumber in a seasoning yard is virtually the same thing as lumber flat piled in the ordinary manner and then tipped up on end. Although the term "end piling" is also used in kiln drying, the piling method is different [17] and, further, end piling in finish sheds is customarily done without the stickers that are essential for green lumber. Just as in flat piling, care should be taken in placing the stickers for end piling so as to avoid warping and end checking, and in providing proper flues or chimneys in the pile.

Some operators in the lower Mississippi Valley maintain that end piling permits the lumber to dry faster than flat piling does. In a certain yard the lumber is end piled for about 15 days, until the surface is dry enough to prevent the development of blue stain, and is then flat piled. In other Mississippi Valley yards the lumber is left end piled until dry. On the other hand, in a yard in which the drying conditions are typical of those in the Appalachian region, end piling was found so unsatisfactory that it has been discarded in spite of the loss involved in tearing down the expensive supports it requires.

END RACKING

There are two common methods of end racking yard lumber. One may be designated as the X form and the other as the inverted-V form. (Pls. 11, C, and 12, A.) Less warping and end checking are likely to occur in the inverted-V form than in the other form and the inverted V is therefore preferred. Another advantage of this method is that stain, if it occurs, is most likely to be at the intersection of the boards, and a smaller loss from trimming results if this defect is near the end than if it is near the middle.

The upper support shown in Plate 12, B, rests on posts braced longitiudinally and laterally, and the lower ends of the boards rest on planks on the ground. Better drying would probably be secured in the lower portions of the boards if they were supported a foot or more above the ground.

The statements previously made (p. 33) concerning the firmness, durability, species, and preservative treatment of wood foundations for flat-piled lumber apply likewise to the supports for the end racking or the end piling of lumber.

It is obvious that the air can circulate much more freely around end-racked than around flat-piled lumber, especially in the vertical direction, and this fact accounts for the more rapid drying that occurs with end racking. After being end racked for from two days to two weeks, stock is usually dry enough to prevent blue stain unless it again becomes wet. When the work is done properly end racking is desirable where stock is especially subject to blue stain. The total length of time that stock is end racked depends on the weather; 3 to 10 days is a usual range. It should be long enough to permit the drying necessary to prevent blue stain and the stock should then be flat piled immediately to keep warping and checking to a minimum.

The species of wood most commonly end racked are sap gum, yellow poplar, and magnolia.

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[17] See footnote 4.

CRIB PILING

Occasionally lumber is crib piled. Such a pile, which is in the form of a hollow triangle, permits rapid drying, but it has the disadvantage of requiring excessive space and the method is liable to result in considerable degrade because of checking, staining, and the warping that comes from lack of support.

DIMENSION STOCK

DEFINITION OF DIMENSION STOCK

Dimension stock is the wood stock of the different sizes and shapes required by wood-using industries in the manufacture of fabricated articles, such as furniture and turnings. It varies in thickness from one-half to 6 inches, in width from one-half to 8 inches, and involves lengths up to 8 feet. Most of the stock, however, consists of sizes less than 3 inches square, or the equivalent in cross-sectional area, and less than 4 feet in length.

To facilitate handling, it is more or less common practice to bundle the smaller sizes.

SOLID BUNDLES

A pile of solid bundles is shown in Plate 13, A. Although the sticks within each bundle are in close contact, the bundles are separated by stickers. This method of bundling is rapid, and it probably holds small squares straighter than when stickers are used within the bundles. If the stock is susceptible to stain, however, this defect is almost certain to develop.

STICKERED BUNDLES

Stickered bundles are shown in the upper part of Plate 13, B. In this type of bundle the air may circulate more freely over each stick so that the rate and uniformity of drying will be better than in a solid bundle. In some species and sizes, however, the tendency to warp is so marked that the resulting degrade is excessive; the amount of the loss involved seems to indicate that in such cases the stock might better be dried in the board or plank form; the lumber could then be recut to any desired size.

COB PILES

In a cob pile the stock is not bundled but is stickered with itself in about the same manner as that of the piles shown in Plate 14, except that the number of pieces in a layer is the same for all layers. Cob piling permits a larger amount of stock to be stored in a given space, but it is conducive to slow drying.

STOCK STICKERS OR SPECIAL STICKERS

The choice of the kind of sticker involves a compromise among economy of space, drying time, and degrade. Obviously, the thinner the sticker the more the stock that can be piled in a given space, and within limits, the thicker the sticker the faster will be the drying rate. The most desirable drying rate will vary with the species of wood and the size of stock; it depends upon whether the dominant defect is likely to be checking or staining. The use of special stickers offers a flexibility in piling, not only in different piles but also within the same pile, that may prove advantageous at times. Further, special stickers can be previously dried, so that the sapwood in contact with the stickers will be less liable to blue stain.

Plate 14, A, is an example of good piling practice where self-stickering is required. The placing of stickers at the ends of the stock and the vertical alignment of stickers are points to be particularly noted because of their tendency to reduce end checking and warping. With squares that are likely to surface check it may be advantageous to minimize this defect by placing each piece so that the quarter-sawed surfaces are horizontal; that is, in direct contact with the stickers. The plain-sawed surfaces, of course, are then vertical, and the adjacent surfaces of all squares in the same layer are close together. By this means the drying of the plain-sawed surfaces may be retarded sufficiently to reduce checking. Ordinarily the danger of checking of quarter-sawed surfaces is negligible.

LAP PILING

Plate 15, A, illustrates a piling method sometimes used for flat stock. Each successive piece overlaps the one below it, so that only two tiers of stickers, one at each end of the pile, are required.

SEASONING SHEDS

Even though stock of a given species may not be subject to blue stain, it may, if exposed to the sun and the rain, become so badly weather stained that the discoloration will not be taken off in machining. With high-grade stock, therefore, seasoning in a shed such as that illustrated in Plate 15, B, may be profitable. As with unsheltered lumber, the foundations should be firm, durable, and high enough to afford adequate circulation of air under the piles.

LATH

Apparently one of the most satisfactory methods of piling lath for air seasoning consists in placing the bundles about 8 inches apart on 2 by 4 inch stickers. The lowest layer of bundles is supported about a foot above the ground, and a tight roof is provided. Such a method is not entirely satisfactory, however, for in damp weather the laths near the middle of a bundle, which usually consists of 50, dry so slowly that they blue stain. In one instance, after air seasoning for 32 days in early fall, the average moisture-content values of a lath from the outside and of one from the center of a bundle were 17 and 182 per cent, respectively. The lath of high moisture content was heavily blue stained throughout its length; the other one was bright. The difficulty in preventing blue stain in lath is probably greater than with a timber of the same size as a bundle of lath, because, if the surface of the timber is dried quickly enough to prevent the stain from getting a foothold, the inside is likely to be free from attack. On the other hand, fungous spores can easily enter the interior of a bundle of lath.

Blue stain in the air seasoning of lath may perhaps be reduced, possibly through a modification of the method of bundling or through chemical dips, but at present the only positive means known for preventing the development of blue stain in lath, as in lumber, is artificial drying.

RAILWAY CROSSTIES

METHODS OF PILING

The general principles involved in preventing decay and checking of lumber are applicable likewise to railway crossties and other timbers. The tie problem, however, is somewhat more complicated than the lumber problem because of the larger size of the individual piece. Thus, the naturally slower drying rate of the interior of crossties, as compared with that of boards and planks, is conducive to the development of decay in untreated ties. Further, the greater difference in drying rate between the inside and the outside of a crosstie tends to cause a larger amount of checking. On the other hand, more checking is permissible in crossties than in lumber of the upper grades, and uniform drying throughout is not required, since in general only the outer part of the tie is treated with preservative, and the primary purpose in seasoning such timbers is to make them take a satisfactory preservative treatment.

Plate 16, A, illustrates the 11 by 11 method of solid-piling; the ties in each successive layer are at right angles to those in the layer beneath. With this method, surface checking is not so likely to occur, because of the relatively slow drying resulting from very slow circulation of air through the pile. The method may be used safely only where there is practically no danger of decay, and in practice is used chiefly for treated ties.

Another type of pile, known as the 10 by 1 form, is shown in Plate 16, B. Because of the more open character of this pile, more rapid drying may occur, with an increased amount of checking and a decreased amount of decay resulting. Somewhat more rapid drying may be expected from still more open piling like the 7 by 2, and similar kinds.

Special stickers to separate the layers of crossties have been used in exceptional cases.

The particular method of piling best adapted to any given seasoning yard depends upon such factors as species of wood, yard site, and weather conditions, and on whether the dominant defect is decay or checking. In one yard where drying conditions are especially favorable and the species of wood involved, lodgepole pine, is not very refractory, surprisingly good results are said to be obtained by piling the ties in rows like cordwood, all pieces being parallel. At each end of each row a crib or a solid pile is erected.

The lowest layer of ties sometimes rests directly on the ground. This practice generally is objectionable because it is liable to result in slow drying and decay. To avoid this difficulty, it is advisable to pile the lowest layer on treated stringers a foot or more above the ground.

Crosstie piles may be 10 to 16 feet high, the spacing between adjacent ties varying from less than 1 inch up to 4 inches. A few companies are erecting piles 30 feet high or more. Often the piles are erected in rows 30 or 40 feet long, with practically no space between piles. The rows, however, are spaced 3 to 5 feet apart.

END COATINGS

Although the use of coatings to prevent the end checking of crossties has not been investigated extensively, it seems quite possible that a moisture-retardant coating, such as roofing pitch or as the filled hardened gloss oil referred to on page 40, may prove advantageous in the seasoning of crossties as well as in that of lumber. To secure the maximum benefit, the coating should be applied before the tie has begun to check. The foregoing relates to the problem from the standpoint of checking only. One operator reports satisfactory results from brush treating the ends of crossties with hot creosote in order to prevent decay; the spots where other ties cross a tie should also be brush treated.

ANTICHECKING IRONS

Two forms of irons designed to hold the ends of crossties intact against checking are in more or less common use; they are known respectively as crinkle irons and S-irons. Which of the two to use appears to be more or less a matter of individual preference.

SEASONING PERIODS

The seasoning time allowed for crossties by different operators varies considerably with the species of wood, as shown in Table 4. The methods of piling, ranging in some instances from 10 by 1 to 10 by 10 for the same species in the same region, appear to vary with the personal preference of the individual operator. The seasoning periods for the same species also show considerable variation, even after allowing for the natural difference between summer and winter rates of seasoning. Of course differences in local conditions, such as wind and humidity, often require great differences in seasoning periods, yet even these factors fail to account for all the variations.

TABLE 4.—*Summary of seasoning periods employed by different treating plants for railway crossties of various species*

Species of wood	Region	Method of piling	Time of seasoning [1]
Beech	Atlantic coast	9 by 1	5 to 8 months.
	Lake States	10 by 4	8 to 12 months.
Birch, yellow	Atlantic coast	9 by 1	5 to 8 months.
	Lake States	8 by 4	6 months.
	do	10 by 4	8 to 12 months.
Douglas fir, coast	Rocky Mountains	do 10 by 1	10 to 12 months.
	do	do	6 to 7 months.
	do	10 by 10	6 months.
	Pacific coast	do	3 months.
	do	do	6 months.
	do	do	10 to 12 months.
Douglas fir, mountain	Rocky Mountains	10 by 1	9 to 12 months.
	do	do	About 6 months.
	do	10 by 10	1 to 1½ months.

[1] When periods of different length are given for the same species the shorter ones include the summer months.

TABLE 4.—*Summary of seasoning periods employed by different treating plants for railway crossties of various species*—Continued

Species of wood	Region	Method of piling	Time of seasoning
Hemlock, eastern	Lake States	10 by 4	8 to 12 months.
Hemlock, western	Rocky Mountains	8 by 4	12 months.
Larch, western	do	10 by 1 10 by 4	9 to 12 months.
Maple	Atlantic coast	9 by 1	5 to 8 months.
	Lake States	10 by 4	6 months.
	do	do	8 to 12 months.
Oak, red	do	do	12 months.
	do	10 by 10	8 months.
Oak, white	Middle West	do	14 to 18 months.
Pine, lodgepole	Rocky Mountains	do	6 to 8 months.
	do	10 by 1	12 months.
Pine, southern yellow	Atlantic coast	8 by 1	3 to 4 months.
Pine, western yellow	Rocky Mountains	10 by 1	6 months.
	do	9 by 1	8 to 12 months.
	do	8 by 4	3 to 4 months.
Spruce, Engelmann	do	10 by 10	6 months.
	do	do	8 to 10 months.

POLES

METHODS OF PILING

In some cases green poles are piled so high and so close together that seasoning is greatly retarded, especially when the lowest layer rests directly on the ground. In order to hasten the drying rate one large producer of poles has developed the method of piling shown in Plate 17. The piers and beams, which are creosoted, support the lowest layer of poles about 2 feet above the ground. Successive layers of poles are separated by treated stickers about 4 inches thick. A chimney 2 feet wide is left in the middle of the pile from bottom to top. The poles, in this case southern yellow pine, are seasoned about two months during the summer or four months during the winter, prior to preservative treatment; in some parts of the United States a seasoning period of four to six months or even more is considered desirable. The time permissible is determined largely by decay conditions.

SEASONING PERIODS

Table 5 gives the reported seasoning periods allowed for air seasoning of poles of several species from the green condition to the average moisture-content values indicated.

TABLE 5.—*Time allowed for air-seasoning poles of western red and northern white cedar and the final moisture-content values*

Species	Locality	Top diameter	Time of seasoning	Final moisture content
		Inches	*Years*	*Per cent*
Western red cedar	Idaho	7	3	15
Do	do	7½	1	21
Northern white cedar	Wisconsin	7½	2	27

Figure 11 shows air-seasoning curves for chestnut poles in a Maryland yard. In this case the final moisture content, although satisfactory, was so high that only a negligible amount of shrinkage had occurred.

TIMBERS

METHODS OF PILING

It has been common practice to bulk pile timbers unprotected, as shown in Plate 18, A. This practice has resulted in heavy losses on account of stain and decay, especially if the timbers were exposed to rain for some time just before being loaded into vessels for long ocean shipment. Some operators, however, are now finding that the cost of properly storing timbers on stickers and under an open shed is well repaid; the timbers are so stored that they have opportunity to dry considerably, at least on the surface. (Pl. 18, B.)

END COATINGS

As with lumber and crossties, the use of moisture-retardant coatings to prevent checks in timbers may be advantageous (p. 40).

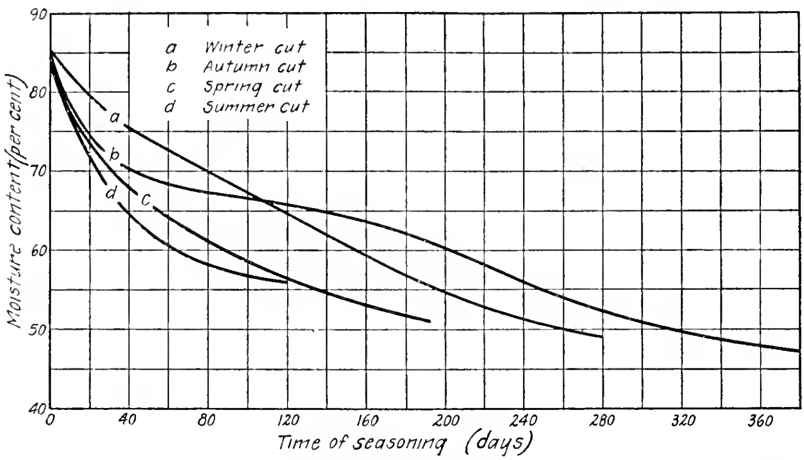


FIGURE 11.—Air-seasoning curves for chestnut poles cut at different times of the year

DRYING DATA

The drying curves for 12 by 12 inch by 24 foot southern yellow pine and Douglas fir timbers, air seasoned in an open shed for two years at Madison, Wis., appear in Figures 12 and 13; these are species commonly used for structural timbers. The timbers were piled on 2 by 4 inch stickers and were spaced 2 to 3 inches apart. The retarding effect of winter weather conditions on the drying rate is very evident.

During July, 1922, the precipitation was 53 per cent above normal, and the sunshine was 18 per cent below normal. On the contrary, in October, 1922, the precipitation was 73 per cent below normal and the sunshine was 33 per cent above. These conditions appear to be reflected in the curves (fig. 12), which show more nearly uniform seasoning during the period July to October than would ordinarily be expected. Likewise, the relatively slow seasoning rate of the Douglas fir timbers during March, 1923 (fig. 12, B), is probably attributable to the fact that during that month the temperature was 19 per cent below normal and the precipitation was 87 per cent above.

POSTS AND CORDWOOD

Posts and cordwood are often piled solidly, all pieces being parallel. This method of course is most liable to produce decay and least liable to produce checking. More rapid drying is likely to result if the pieces are piled in the form of a hollow square, the so-called log-cabin style. This method is liable to bring about an increase in the amount of checking, but with cordwood checking is not objectionable; the chief disadvantage of the method is that it requires a great deal of space. A modified log-cabin piling gives almost as good results and occupies much less space. In the modified method the pile is self-stickered, each layer resting on single pieces at opposite ends of the pile. (Pl. 19, A.)

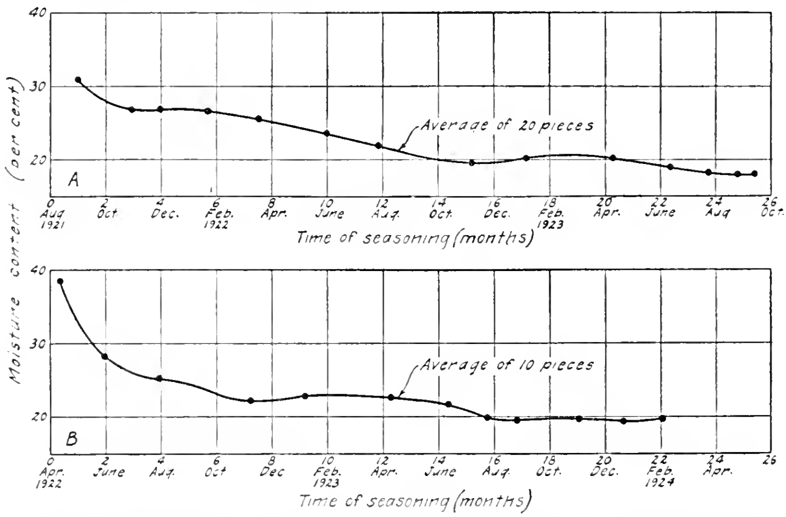


FIGURE 12.—Air-seasoning curves for southern yellow pine heartwood timbers 12 inches square by 24 feet long, seasoned in an open shed. The stickers were 2 by 4 inch and the timbers in each layer were spaced 2 to 3 inches apart

COOPERAGE

STAVES

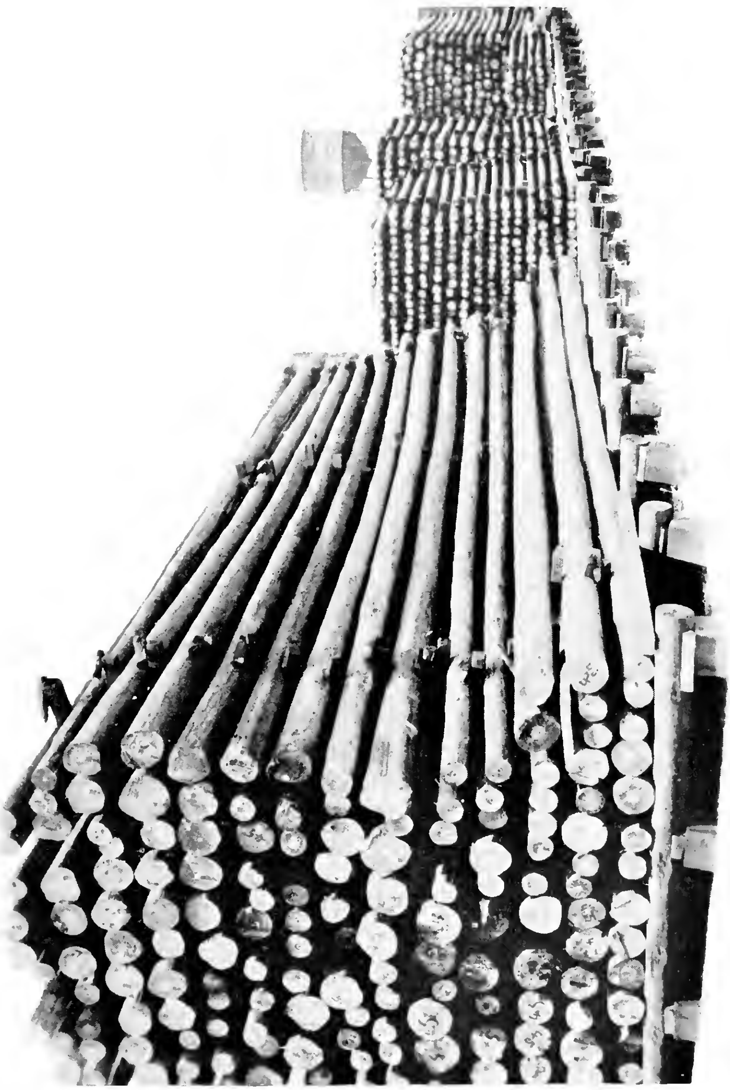
The piling of staves in the form of a hollow square to secure rapid drying is shown in Plate 19, B. With this method of piling, 90 days is ordinarily required to air season 2-inch staves satisfactorily. The staves are half-lapped, so that the weight of the upper ones does not tend to change the desired curvature of those supporting weight.

HEADING

A method of open piling, which is particularly adapted to heading, is shown in Plate 20, A. Here the pieces are piled approximately in the form of a hollow cylinder. In some instances the top of the pile is built up in the form of a cone for the purpose of providing some protection against rain.

VENEER

Only a relatively small amount of veneer is air seasoned. Most of it is dried either in standard dry kilns or in special mechanical driers.



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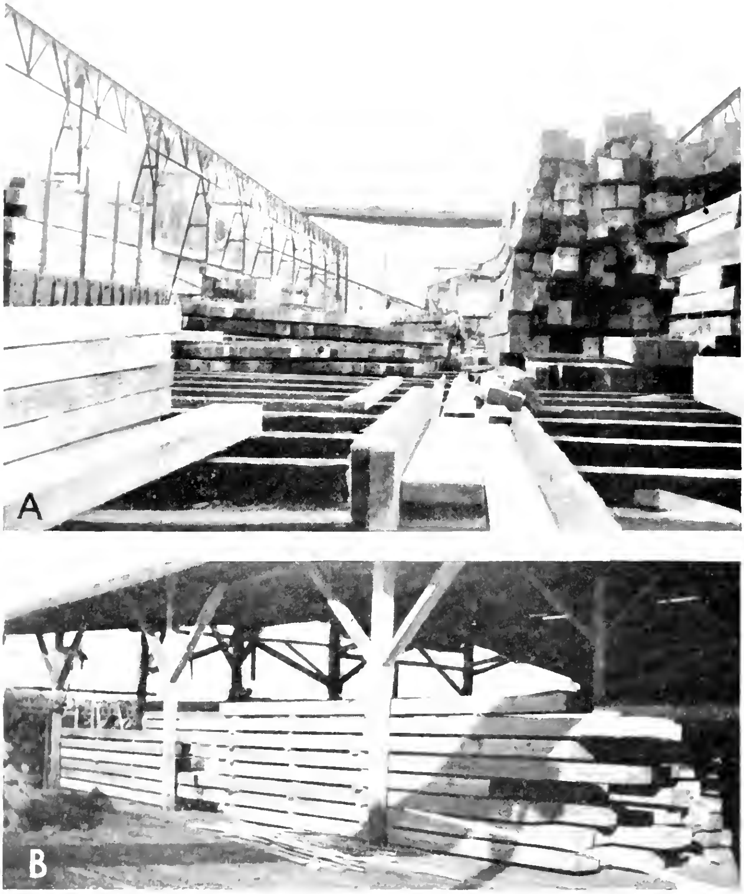
Well-piled poles in an air-seasoning yard. Each pile is high above the ground on treated piers and stringers. Heavy stickers, also treated with preservative, separate successive layers. The sanitation is excellent



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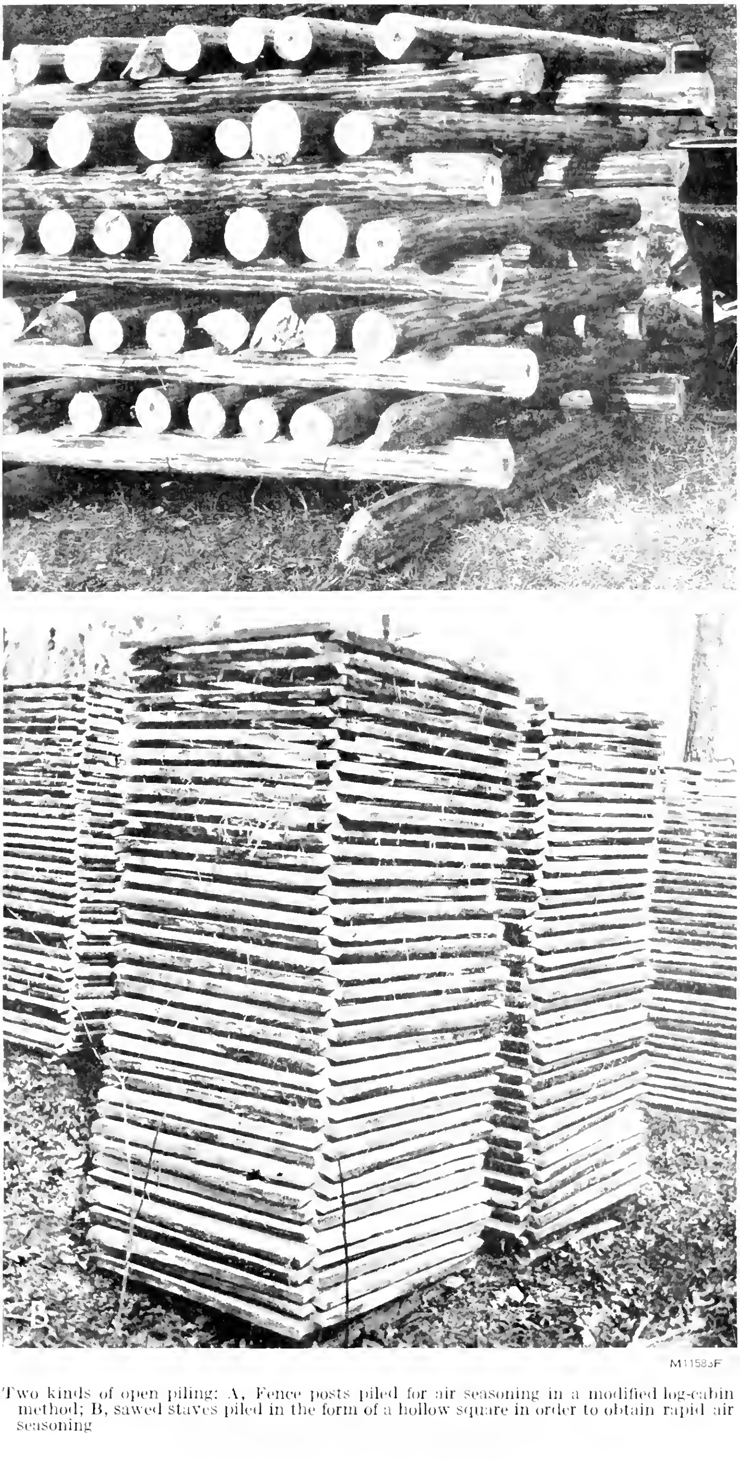
Common practice and good practice in temporary storage: A, Lumber and timbers, in temporary storage, bulk piled unprotected in a loading yard; B, timbers stored temporarily on stickers and under protection from rain and snow, in order to obtain rapid seasoning for the purpose of reducing the likelihood of stain and decay developing during long water shipment



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Two kinds of open piling: A, Fence posts piled for air seasoning in a modified log-cabin method; B, sawed staves piled in the form of a hollow square in order to obtain rapid air seasoning

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A, Oak barrel-heading stock piled for air seasoning in the form of a hollow cylinder; B, thick veneer stock end piled for air seasoning under a double roof; C, veneer stock flat piled for air seasoning

Two methods of piling thick veneer for air seasoning are shown in Plate 20, B and C. In the first method the courses of veneer are stacked on end, separated by stickers, and are given some protection from sun and rain by a roof. One modification of this method was observed in which the stickers were vertical and the pieces of veneer were racked on edge. In the second method the veneer is flat piled on stickers in a manner similar to that in which boards are commonly piled. A third method is to suspend the sheets.

DRYING RATES AND FINAL MOISTURE CONTENT

EFFECT OF CLIMATE

As already explained (p. 17), temperature and humidity affect both the drying rate and the equilibrium moisture content of wood. From this it follows that a hot, dry climate, such for example as

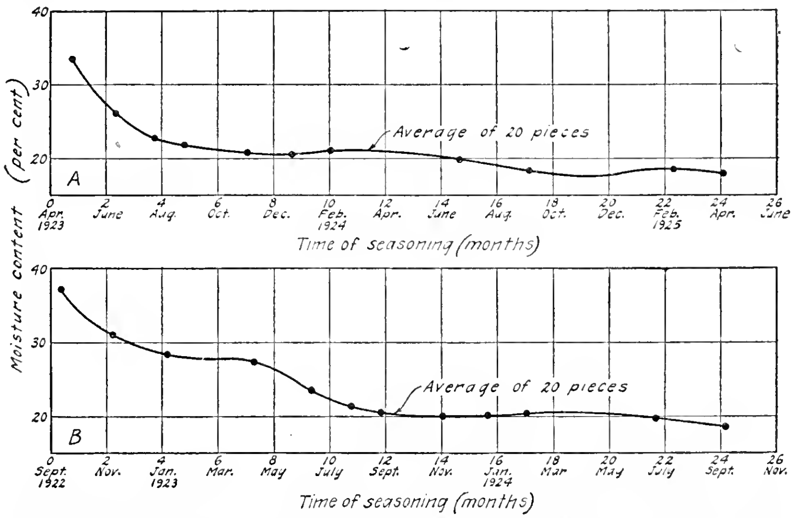

FIGURE 13.—Air-seasoning curves for Douglas fir heartwood timbers 12 inches square by 24 feet long, seasoned in an open shed. The stickers were 2 by 4 inch and the timbers in each layer were spaced 2 to 3 inches apart

that which prevails in the Southwest, is much more conducive to a rapid drying rate and lower final moisture content than, for instance, is the damp climate of the redwood region of California.

EFFECT OF SEASON OF YEAR

The influence of summer and of winter conditions on the drying rate and the final moisture content of wood is clearly shown in Figures 12 and 13, which have been discussed previously. In another instance some 1-inch birch boards were air seasoned from the green condition to a moisture content of 15 per cent in about six weeks during the summer, but during the fall they absorbed moisture, and by December 1 the moisture content had increased to 20 per cent.

EFFECT OF SPECIES OF WOOD

Some species of wood differ markedly in their rates of drying. In northern Wisconsin, for example, 1-inch basswood is reported to dry in about one month less time than 1-inch maple does. The maximum difference in the final moisture-content values of 1-inch boards of the various common species, however, is probably not more than 2 per cent when the boards are subjected to the same air-seasoning conditions for a time sufficient to bring them to equilibrium conditions.

EFFECT OF THICKNESS

Some 2-inch southern swamp white oak planking required 270 days to air season from 70 to 23 per cent moisture content at Madison, Wis. Under similar conditions the corresponding drying time for 4½-inch oak wagon bolsters was 464 days. After 379 days of seasoning the final average moisture content of the 2-inch plank was 16 per cent and after 710 days the corresponding moisture content of the 4½-inch bolsters was 19 per cent. Records for certain western softwoods indicate that 1-inch stock may air season in half the time required by 2-inch stock of the same species. An approximate rule appears to be that the rate of air seasoning for different thicknesses of stock of a given species ranges from the proportion

$$\frac{R_1}{R_2}=\frac{T_1}{T_2}$$

to the proportion

$$\frac{R_3}{R_4}=\sqrt{\frac{T_3}{T_4}}$$

in which the T's represent respective thicknesses and the R's represent respectively the corresponding drying rates. The rule applies to thicknesses not less than 1 inch and not exceeding 4½ inches.

Data sufficient to show the effect of air seasoning on the equilibrium moisture content of stock of different thicknesses are not available. In a series of experiments on partially air-dry white ash, however, the pieces were exposed in a room at approximately 80° F. and 90 per cent relative humidity. The 1-inch stock then absorbed moisture up to an average value of 23.8 per cent, while the 3½-inch stock reached a moisture content of 23.3 per cent under the same conditions. When the stock was dried in a chamber at 120° and 28 per cent relative humidity, the corresponding moisture-content values of the 1-inch and the 3½-inch pieces were 5.8 and 6.5 per cent, respectively. So far as white ash is concerned, therefore, it appears from the foregoing that thickness has a negligible effect on equilibrium moisture content under the constant conditions noted. On the other hand, if the stock were exposed where the temperature and the humidity fluctuated through a considerable range and remained uniform only for brief periods, the effect on the moisture content of the interior of a thick piece might be reduced. Consequently, the average equilibrium moisture content of a thick piece might remain higher (or lower) than that of a thin piece of the same wood in localities where the weather changes frequently.

EFFECT OF SAPWOOD AND OF HEARTWOOD

The curves in Figure 14 indicate the change in moisture content of loblolly pine cross arms, both sapwood and heartwood. Initially the sapwood cross arms had about twice as much moisture as the heartwood, but at the end of five weeks both had reached the same moisture content. At the end of six months the moisture content of the sapwood was 23 per cent, while that of the heartwood was 31 per cent. If the experiment had been continued for another six months, it is probable that the difference in moisture content would have been much smaller. With some species the upper grades contain more sapwood than heartwood, and in order to secure the most rapid drying rate for such grades it may be advantageous to segregate them from the lower grades.

EFFECT OF LOCALITY OF GROWTH

Data covering the comparative air-seasoning rates of drying and the final moisture-content values of boards cut from trees of a given species, grown in different localities, are not available. In kiln

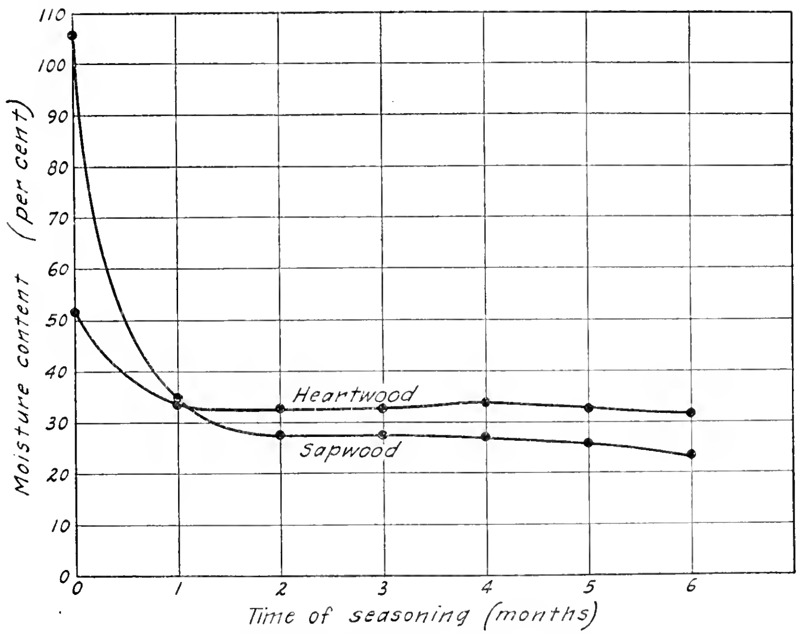

FIGURE 14.—Air-seasoning curves for loblolly pine cross arms of heartwood and of sapwood, 3¼ by 4¼ inches by 10 feet

drying, however, it has been found that southern swamp white oak dries much more slowly than northern highland white oak does. It seems probable that a similar difference would exist if the two kinds of stock were air dried, and also that the difference in equilibrium moisture content would be of no practical importance.

EFFECT OF YARD LOCATION AND ARRANGEMENT

In Louisiana are two hardwood yards owned by the same company and located about 10 miles apart. One is at a slightly lower elevation than the other and is surrounded with trees, which tend to reduce the air movement through it. This yard is approximately square, while the other one is relatively long and narrow, with its long dimension across the direction of the prevailing wind. As would be expected, the conditions in the square yard result in a slower drying rate than do those in the narrow one.

In another Louisiana hardwood yard piles of various lengths were located side by side under conditions the same except for pile length and relative position. It was noticed that where a 10-foot pile was to leeward of a 16-foot pile, the circulation through the short pile was retarded sufficiently by the obstructing pile to cause more blue stain in it than in the obstructing one. In addition to the retarded circulation, the slower drying of the 10-foot pile may in some measure have been caused by a higher humidity resulting from the moisture carried over from the windward pile. Although actual data in this instance are not available, it is probable that the final moisture content of the 10-foot pile was appreciably higher than that of the 16-foot pile.

Although the two cases just cited were in a particular locality, the factors mentioned are likely to have an important effect on the air seasoning of lumber in other regions.

SELECTION OF THE PILING METHOD

The effect of piling methods in reducing check, blue stain, and decay has been discussed in a previous section. Further, the point has been made that a piling method that permits rapid drying is liable to cause checking, and also that too slow drying is conducive to the development of blue stain and decay. The various factors that bear on the choice of a piling method are summarized in Table 6.

TABLE 6.—*Piling methods that minimize the occurrence of the more common air-seasoning defects*

Location of defect	Procedure for reducing the occurrence of—		
	Blue stain and decay	Checking	Warping
Throughout the pile	Raise the foundations. Increase the spacing between boards and between piles. Provide one central flared chimney or a series of narrow chimneys. Use thicker, narrower stickers. Narrow the piles.	Lower the foundations. Decrease the spacing between boards and between piles. Use thinner, narrower stickers. Place the end stickers so that they project beyond the ends of the pile. Use end coatings and antichecking irons.	Use stickers of uniform thickness, properly aligned and supported, and sufficient in number.
The lower part of the pile only.	Provide short chimneys (one-third or one-half height of pile). Use thicker stickers in the lower part of the pile.		

SPECIAL TREATMENTS

PRELIMINARY STEAMING

The usual object of steaming lumber before it is piled in the yard is to heat the stock so that when it is piled outdoors the surface will dry rapidly to the point at which blue-stain fungi can not develop. This point, according to present information, is approximately 20 per cent moisture content. If the lumber is exposed to damp weather immediately after the steaming process, however, the desired drying can not occur, and consequently stain is likely to result. Similarly, the desired drying does not occur if the stock is handled improperly immediately after the period of steaming; the stock must be open piled just as soon as it is cool enough. Preliminary steaming at 180° F. and 100 per cent relative humidity for four hours per inch of thickness is effective also in killing any fungi already present in the green stock.[18]

Preliminary steaming for the foregoing purposes is advantageous with the sapwoods of red gum, poplar, and magnolia. On the other hand, such steaming is very detrimental with such woods as cypress and oak, because of their marked tendency to check.

It is common practice to steam the sapwood of black walnut so that its color will be darkened and will more nearly resemble that of the heartwood.

DIPPING

Many southern yellow pine mills have equipment for dipping green lumber in a solution of a chemical, such as sodium carbonate or sodium bicarbonate, or a mixture of such chemicals. This treatment appears to reduce the danger of blue stain during subsequent air seasoning. The exact nature of the action of the alkaline chemical is not definitely understood, but the alkali is supposed to counteract the wood acids that are favorable to the development of blue stain. In dry weather a 4 per cent water solution and in damp weather an 8 per cent water solution of sodium carbonate is considered satisfactory; the corresponding figures for sodium bicarbonate are 5.5 and 11 per cent, respectively. With either alkali the solution should be kept at 140° F. The concentration and the temperature of the solution appear to be important factors in securing the best results; these factors may change materially during use of the dip, and hence should be observed frequently. When necessary they should be returned to their proper values.

At some mills the green chains carry the boards to and from the dipping tank, while at others the boards are conveyed on dollies from the green chain to the dipping tank.

Both spraying and dipping are used also for southern yellow pine timber. Dipping only is occasional in several lumber regions.

STORAGE OF DRY LUMBER

GENERAL

Previous discussion in this bulletin has emphasized the importance of having the moisture content of lumber suitable for the use requirements of the stock. Obviously the moisture content of stock as it is placed in service is affected by the practice of the manufacturer, the wholesaler, the retailer, the fabricator, and the contractor. Any one of these five can undo to some extent the good work of the others. It will avail little, for example, to have the first four follow correct practice if the last one then nullifies their results by

[18] Further details are given in Department Circular 421 (*3*).

subjecting such items as flooring, doors, window frames, and sash to weather conditions. Ordinary atmospheric conditions cause an increase in the moisture content of lumber properly dried for interior use, and then shrinkage occurs when the heating system of the completed building is put into operation. Cracks in floors and around windows and doors certainly are not an asset in maintaining satisfaction in the use of lumber, and neither are warped doors.

On the other hand, if the manufacturer dries the lumber improperly any or all of the others who handle it can improve the moisture condition of the stock considerably by means of heated storage. The retailer or the fabricator, for instance, can largely and sometimes completely correct through heated storage any improper moisture treatment by the manufacturer or the wholesaler. Purchase specifications, which should be employed, will place definitely the responsibility for final results that is now divided at random among all those who contribute to the finished product.

OPEN YARDS

Since in most regions there is considerable difference between summer and winter values of equilibrium moisture content, it may be advantageous in some cases to bulk pile in the yard stock that has become thoroughly air-dry during the summer, in order to prevent or to reduce the absorption of moisture during the winter. If, however, the locality under consideration is subject to heavy snows or driving rains, a better practice is to allow the stock to remain on stickers. In either case a tight roof should be provided.

SHEDS

Piling stock within a shelter obviously affords it protection better than the best possible in an open yard. In Plate 21, A and B, are shown the exterior and interior of a shed adapted to flat bulk piling.

Some of the studies previously referred to in this bulletin have indicated the reasons for variation in the moisture content of lumber when it is taken from the yard. Other studies have indicated the range in moisture content of air-dried and of kiln-dried softwoods; when the average moisture content is the same, the range is greater for the kiln dried than for the air dried.

Additional data pertaining to certain softwood sawmills are available to show that, if the stock is bulk piled in a closed storage shed, the range in moisture content can be materially reduced. For instance, numerous moisture-content values determined for certain grades of kiln-dried softwood flooring ranged from about 2 to 30 per cent, with an average of 7.1 per cent. After being bulk piled for 30 days in partly open sheds the range was from about 2.5 to 16.5 per cent, with an average of 8.5 per cent. Further, the increase in moisture content of lumber in sheds may be less than if the stock is stored in yards. Incidentally, an added advantage of bulk piling in a closed shed is that the lumber is kept cleaner than when it is exposed to rain and dust.

HEATED STORAGE

If, after air seasoning or kiln drying, it is necessary to prevent an increase in moisture content, the desired result can be accomplished by bulk piling or by open piling the stock in a heated building. The same means may be employed also to reduce moisture content. When this result is desired the stock should be piled on stickers rather than bulk piled, if the duration of the storage period is to be minimized. Such a method of drying is particularly suitable where dry kilns or skilled operators are not available. It is also advantageous where a high degree of refinement in the quality of the finished product is necessary. Such excellence is essential, for instance, in fine handwork and in instruments of precision. With articles like jewel boxes, level rods, and slide rules, for example, in which nicety of construction, appearance, and service are prime requisites, the cost of drying the material properly is negligible in comparison with the value of the finished product.

As an offset to the saving in time that would be obtained by kiln drying, the simplicity of equipment and operation of heated storage may in some cases prove an important consideration. Probably it is feasible to maintain or even to attain a considerable range of desired moisture-content values, corresponding to certain relative humidities, simply by controlling the temperature, which in most cases would probably be from 50° to 100° F.; the relative humidity of the air, and in consequence the moisture content of the stock, would decrease as the temperature increased.

Gas-burning or oil-burning equipment is a convenient boiler accessory for heated storage, especially on those days when heat is required to control the moisture content of the lumber and for no other purpose.

Plate 22 illustrates a portion of the interior of a heated brick building in use by a wholesale distributor of hardwood and softwood lumber. Plate 22, C, shows the arrangement of the wall radiators, and Plate 22, A and B, indicate the method of bulk piling hardwood flooring about 3 inches above the concrete floor and with an occasional layer of stickers to stabilize the pile. If at all feasible to do so, it would be better to pile the stock at right angles to the position shown and several feet from the wall radiators. Such a change in the position of the pile would permit air to circulate more readily under the pile and toward the radiators, thus keeping the lower layers of stock drier and at the same time preventing overdrying of the ends of the boards. This building stores both air-dried and kiln-dried stock; for a quality product, heated storage is desirable from every point of view.

ADDITIONAL DETAILS

SPECIFIC GRAVITY AND WEIGHT OF WOOD

In the last three columns of Table 3 are given the average specific gravity (based on oven-dry weight and green volume) and the weight per cubic foot of green wood and of wood at about 12 per cent moisture content for clear samples of various species growing in the United States. Because of variations in the actual size of pieces of lumber of the same nominal size and for other similar reasons the figures can not be used to calculate accurately the reduction in weight of lumber during seasoning. They are useful, however, in making rough estimates of this factor.

CHANGE IN MOISTURE CONTENT OF LUMBER DURING RAIL TRANSIT

Studies on carload shipments of air-dry western white pine and white fir from the Inland Empire[19] to the Chicago territory have shown negligible changes in moisture content during transit. The moisture-content values at the time of shipment ranged from 15 to 22 per cent and the changes in moisture content during transit ranged from a gain of 0.2 to a loss of 2.4 per cent, the change in most cases being less than 2 per cent. The conclusion was reached that if stock at a satisfactory moisture content is loaded into a tight box car, the stock will reach its destination in practically the same moisture condition.

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[19] See footnote 5.

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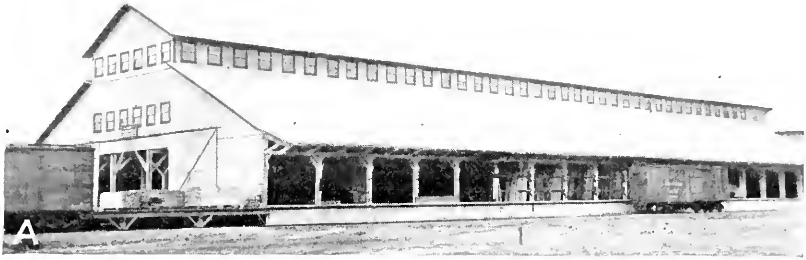

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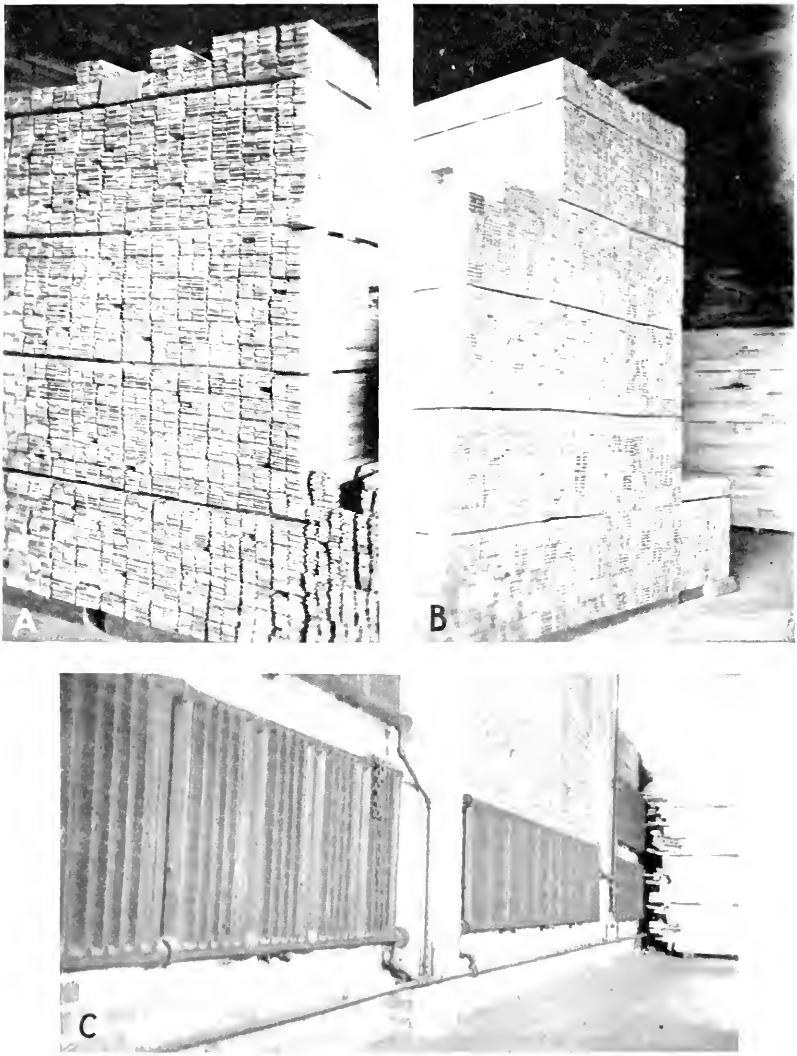
Storage of seasoned lumber under shelter: A, The exterior of a storage shed suitable for air-seasoned lumber, showing its one open side; B, a part of the interior of the same well-built shed. The lumber is bulk piled flat on stringers, with heavy stickers separating successive piles; additional stringers at the ends of the piles might be better practice than the small number now used



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Heated storage of finished lumber: A, End-matched oak flooring, bulk piled on stringers with stickers about every 24 layers; B, twine-bound bundles of end-matched maple flooring; C, wall radiators for heating storage space

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TECHNICAL BULLETIN No. 173 FEBRUARY, 1930

UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

THE BLUEGRASS WEBWORM[1]

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CONTENTS

INTRODUCTION

Although the bluegrass webworm, *Crambus teterrellus* Zincken, is widely distributed throughout the eastern part of the United States, its comparatively small size and inconspicuous coloring seem to have rendered it almost immune from the attention of entomologists. Over a portion of its range it is probably the most abundant of all Lepidoptera during much of the summer, and yet scarcely two pages have ever been written about its life history and habits. Murtfeldt made some observations on it in the summer of 1892 (*14*),[4] her attention being attracted by its great numbers. Practically all other published allusions to it are mere records of occurrence, and its complete bibliography comprises hardly more than a score of references. Since it is of considerable economic importance the writer has assembled here all the available information relative to this species.

Although this insect is perhaps not more strictly limited to bluegrass for food than are some other species of the genus, the common name given it by Murtfeldt has here been adopted with slight change. The name seems fitting because over the limestone districts of central Kentucky and Tennessee, where the insect is a dominant species, Kentucky bluegrass is also one of the dominant plant species. Although locally abundant during favorable seasons at points far removed from this territory, it probably is more continuously abundant over the bluegrass regions of Kentucky and Tennessee than in any other part of its range.

[1] This bulletin constitutes No. VI of the series of Contributions to a Knowledge of the Crambinae of North America. No. I, *Crambus hemiochrellus* Zeller, appeared in Annals of the Entomological Society of America for March, 1918, and II, *Crambus laqueatellus* Clemens, appeared in the June, 1922, issue of the same journal. The third paper, entitled "Striped Sod Webworm, *Crambus mutabilis* Clemens," appeared in the Journal of Agricultural Research, Vol. XXIV, No. 5, and the fourth, "The Silver-Striped Webworm, *Crambus praefectellus* Zincken," followed in the same number. No. V was published as U. S. Department of Agriculture Technical Bulletin No. 31, entitled "The Larger Sod Webworm."

[2] Resigned Jan. 31, 1927.

[3] Meager facts already in print have been freely utilized, but the great majority of the data are the results of several years' study by the writer, assisted by various men, of whom C. C. Hill, and especially W. B. Cartwright, deserve mention for their efficient cooperation.

[4] Italic numbers in parentheses refer to Literature cited, p. 24.

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SYSTEMATIC HISTORY

Crambus teterrellus was first described by Zincken (*21, p. 252*) in 1821, and placed in the genus Chilo, which at that time comprised substantially all of our present subfamily Crambinae. His specimens came from the vicinity of Savannah, Ga.

No further reference seems to have been made to this species until it was redescribed in 1860 by Clemens (*6, p. 203*) as *Crambus camurellus*. Zeller quickly noted this error, and in 1863 (*18, p. 27*) reduced the new name to a synonym, a decision in which all later writers have concurred. Ascribing the first syllable "te" to a typographical error, Zeller (*18, p. 27*) changed Zincken's original *teterrellus* to *terrellus* and so used it in all of his references to this insect (*19, p. 539; 20, p. 35*). Grote (*11, p. 78*), and Smith in his earlier lists (*15, p. 346; 16, p. 468*), used the spelling *teterellus*, but since then, without exception, the original form has been employed.

Until 1893 all references in literature to this insect were purely systematic, being either descriptions or records of occurrence. In that year, however, there appeared from the pen of Murtfeldt (*14, p. 53–54*) a short article giving a brief account of the insect's larval habits as observed by her near St. Louis. The following year Felt (*7, p. 66–67*) summarized Murtfeldt's paper and quoted liberally from it, but added nothing to her facts. From that time until now, except for some brief accounts by the present writer (*1, p. 116, 118; 2, p. 114–123; 3, p. 12*) nothing concerning the bionomics of this species has appeared. It has of course been included in check lists and catalogues; and various authors, including Hine (*12, p. 26*), Gillette (*9, p. 11*), Laurent (*13, p. 170*), Brimley (*4, p. 41*), Smith (*17, p. 530*), and Britton (*5, p. 107*), have recorded its occurrence in different States.

GEOGRAPHICAL DISTRIBUTION

The writer has been able to assemble a great number of occurrence records for this species and to determine with some accuracy the limits of its distribution. The westernmost records are from San Diego, Tex., Golden and Fort Collins, Colo., and Sioux City, Iowa. The northern limit is a line running almost due east from Sioux City. Hine (*12, p. 26*) reports that it occurs "only sparingly" in Ohio, although it has been taken as far north as Columbus. Felt (*7, p. 66*) states definitely that it is found in New York State, though it is not present in Ithaca; it evidently must occur only in the southeastern portion of the State. It has been taken on Nantucket Island, off the coast of Massachusetts. Grossbeck (*10, p. 125*) says that it "extends to Maine, Missouri, and Texas," but no definite record from Maine is known to the writer. Extensive collections of Crambinae in Minnesota and the Dakotas have failed to reveal its presence in those States. Although it has not been recorded from there, it doubtless occurs in at least a portion of Nebraska. There are dependable records of its presence in every State south and east of the limits above named, except Oklahoma, Delaware, and Rhode Island, in all of which it doubtless occurs. The southernmost points from which records have been received are Brownsville, Tex., and Miami, Fla. In 1887 the late F. M. Webster noted the insect as "excessively abundant" at Ashwood, La., and Forbes (*8, p. 220*) records it as "the dominant species in Alabama, Mississippi, and Louisiana."

The accompanying map (fig. 1) shows at a glance the territory at present known to be inhabited by this species.

Over some portions of this territory the species is not prominent, but throughout a section including Tennessee, Kentucky, and southeastern Missouri, and possibly in places in other States, it is the dominant species during practically the entire summer, greatly exceeding in numbers all other species of Crambus combined. In the States to the north of the Ohio River its preponderance is usurped by *Crambus trisectus*.

The following list names the States from which occurrence records have been obtained, together with the month and day of month of first and last records and the intervening months in which the moths have been reported. A query denotes uncertainty as to date. The list is very incomplete, but will serve as a basis for future work.

State	*Month and day*
Alabama	?
Arkansas	June 24, August 11.
District of Columbia	June 3, August, September.
Florida	February 12, April, May, June, July 3.
Georgia	?
Illinois	May 24, June, July, August, September, October 9.
Indiana	June 28, July, August, September, October 5.
Iowa	July 5.
Kansas	July 27, August 8.
Kentucky	June 9, July, August 11.
Louisiana	April 17, July 24.
Maryland	August 7–30
Massachusetts	?
Mississippi	May 16, June, August 3.
Missouri	May ?, June, July, August 16.
New Jersey	June 3, July, August, September 1.
North Carolina	May 19, June, July, August 15.
Ohio	August 28.
Pennsylvania	June 20, July, August, September 12.
South Carolina	September 10–12.
Tennessee	May 3, June, July, August, September, October 16.
Texas	March 2, April, May, June, July, August, September, October 7.
Virginia	July 15, August, September 23.
West Virginia	?

ECONOMIC IMPORTANCE

Judging from the slight attention paid by economic entomologists to the bluegrass webworm, one would naturally conclude that it causes little or no damage. This, however, is not the case. A species present in such great abundance as this one often is, and using as its primary food a grass as valuable as Kentucky bluegrass, must certainly cause appreciable loss, but loss difficult or impossible to estimate with any degree of accuracy. Here is found the explanation of the slight attention the insect has received. The injury is so insidious that undoubtedly there are thousands of farmers who lose seriously every year and yet do not know that such a pest exists, and have never seen any stage of it except the adult. The principal injury is suffered by pastures, meadows, and lawns. During seasons of abundant rainfall the plants themselves are seldom injured, and the only loss is the actual quantity of grass eaten by the worms, but this is no inconsiderable item. During dry periods in midsummer, however, there is not only the loss from the grass eaten but also, and more serious, the injury to the plants themselves. When the plants are having difficulty in maintaining themselves and are without opportunity to recuperate, the extra drain to which they are put in having every green shoot and particle of leaf searched out and eaten kills all but the very strongest.

Considerable areas of bluegrass pasture are often seen which are completely dead, or have only an occasional living plant when rains finally give relief. Coming at times of drought, this injury is usually, and quite naturally, ascribed to drought alone; but without doubt the damage is greatly accentuated by the presence and work of the larvae here discussed. The writer has no record of injury caused by this species to cultivated crops, and its destructiveness seems to be limited entirely to areas more or less permanently in sod.

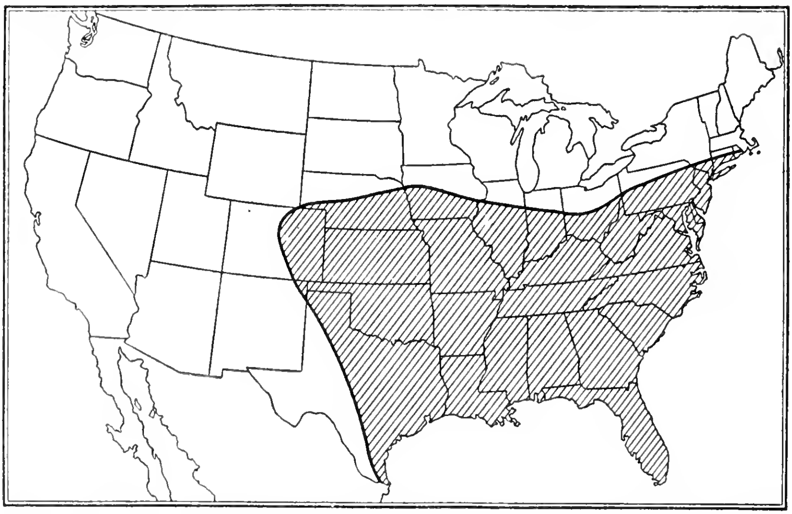

FIGURE 1.—Map of the United States, showing the known distribution of the bluegrass webworm, *Crambus teterrellus*

SEASONAL HISTORY

Murtfeldt (*14, p. 53*) states that the moths are most abundant "about the first of August." Felt (*7, p. 66–67*), apparently misreading this statement, says that "the adults do not fly till August." Both of these authors are evidently of the opinion that there is only one generation annually, the insects hibernating as partly grown larvae.

In Tennessee, where the only fairly complete studies of this species have been made, the first flight of moths occurs early in May. These are the moths developing from the overwintering larvae, and the exact date of their appearance varies but slightly from year to year. After their first appearance they increase rapidly in numbers, and throughout the month they are common, and often exceedingly abundant, in every grassy place. During June their numbers gradually decrease, and toward the latter part of the month, especially if the season is dry, there is sometimes a period of several days in which they are scarce or absent.

Early in July the moths of the second flight appear. They rapidly increase in number and continue abundant throughout the rest of the month and in August. Although moths are present continuously through August, they decrease in number during the middle and latter part of the month. In September, unless seasonal conditions interfere, there is a third fresh emergence. The moths rapidly disappear toward the end of this month, and after October 1 a specimen is rarely seen. The latest available record of their appearance in Tennessee gives the date as October 16.

In Tennessee, therefore, there seem to be three broods each year, the moths maturing in May, July, and September, respectively. The first flight of moths in May is fairly distinct; after it there is a rather definite pause before the appearance of the second flight. The interim between the second and third flights, however, is not so marked, and scattering individuals are usually present during August. The variation in the time required for development is so great that toward the end of the season the generations overlap to a considerable extent. The data obtained from rearing cages fully bear out the conclusion, derived from field studies, that three generations annually are possible.

The time of appearance and the abundance of the moths are also affected to a noticeable degree by meteorological conditions. A very hot, dry period of three weeks or more at any time during the summer causes a great reduction in the number of moths present, and copious rains succeeding such a period are followed at an interval of a week or 10 days by the appearance of a large number of freshly emerged moths. Apparently the larvae approaching or reaching full development during such a dry period lie quiescent for some time, instead of pupating immediately, but resume their development when supplied with moisture. It has also been observed that during a season having plentiful and well-distributed rainfall the moths appear in much greater numbers than during one with insufficient or irregular rainfall. It is evident that a continuous growth of young, tender grass is essential to the welfare of the larvae, especially while they are small, and that the mortality is very great among larvae hatching when the ground is dry and hot and the grass rough and closely cropped. It may well be, however, that in spite of their smaller numbers at such a time, the damage actually done to the grass plants is really greater during a dry season than during a rainy one; for then the grass plants need all their vitality to keep alive, and the presence of hordes of hungry larvae industriously searching for the least particle of succulent growth makes it certain that the plants will be given no respite until the larvae either starve or disappear, or renewed rains improve conditions of growth.

LIFE HISTORY

Nearly 200 individuals of this species were reared from egg to adult in 1915 and 1916, and more or less complete records were kept of the duration of the various stages. After preliminary experimentation two types of cages were adopted as satisfactory for this work. The first, an ordinary 4-inch flowerpot, containing a small sod of bluegrass, covered with a lantern globe closed at the top with a sheet of muslin, served for general rearing when the total length of the combined larval and pupal stages was being observed. The other type, a tin salve or ointment box of ½, 1, or 2 ounce capacity floored with several disks of damp absorbent paper which served to prevent drying out, or the accumulation of excessive moisture, was used when it was desired to keep the larvae under practically constant observation, as in determining the number and duration of the separate instars. Food was supplied to these boxes in the form of leaves of the food plant, cut into short pieces and laid on the blotter. These tin boxes have proved very useful in all the rearing work with crambid larvae, for without disturbing the larvae it is possible to observe the preparation for a molt, to make any measurements or descriptions desired, and to find the discarded head capsule after ecdysis.

In all the rearing work *Crambus teterrellus* has shown greater variation in every way than any other species studied. In number and duration of the various instars, and in the total time required from the hatching of the eggs to the emergence of the adults the variation is so great that averages are of little value. For this reason it has been thought best to present the data as is done in Table 1 rather than to attempt to condense them.

TABLE 1.—*Observations of stages of the bluegrass webworm reared in cages*

Cage No.	Date eggs were laid	Date eggs hatched	Egg stage	Date of pupation	Larval stage	Date adults out	Numbers and sex	Pupal stage	Total extent larval and pupal stages	Food
			Days		*Days*			*Days*	*Days*	
16102[1]	?	May 14	?	?	?	July 11	1♀	?	58	Bluegrass.
						July 12	1♀		59	Do.
						July 16	2♂		63	Do.
						July 18	1♀		65	Do.
						July 20	1♀		67	Do.
						July 24	1♀		71	Do.
						July 25	1♀		72	Do.
						July 28	1♂		75	Do.
						July 31	1♀		78	Do.
						Aug. 3	1♀		81	Do.
						Aug. 7	1♀		85	Do.
						Aug. 8	1♂		86	Do.
						Aug. 12	2♂		90	Do.
						Aug. 26	1♂		104	Do.
						Aug. 27	1♂		105	Do.
12354G	May 21	May 27	6	?	?	July 6	1♂	?	40	Do.
						July 8	1♂		42	Corn.
19135	?	June 3	?	?	?	July 28	2♀	?	55	Bluegrass.
15281	?	June 12	?	July 19	37	July 26	1♂	7	44	Bluegrass and corn.
15285	June 6	do	6	July 22	40	July 31	1♂	9	49	Corn.
				July 23	41	do	1♀	8	49	Do.
				July 26	44	Aug. 2	1♀	7	51	Bluegrass.
				July 28	46	Aug. 3	1♀	6	52	Corn.
				July 30	48	Aug. 4	1♀	5	53	Do.
				Aug. 10	59	Aug. 18	1♀	8	67	Bluegrass.
15311	June 17	June 22	5	July 26	34	Aug. 2	1♂	7	41	Do.
				July 27	35	do	1♀	6	41	Do.
				Aug. 6	45	Aug. 13	1♂	7	52	Do.
				Aug. 9	48	Aug. 17	1♀	8	56	Do.
				Aug. 21	60	Sept. 3	1♂	13	73	Do.
17109	June 23	June 28	5	?	?	Aug. 21	5♂	?	54	Do.
						Aug. 23	3♂, 1♀		56	Do.
						Aug. 28	5♂, 2♀		61	Do.
						Sept. 14	1♂		78	Do.
15326	?	July 2	?	?	?	Aug. 10	1?	?	39	Do.
						Aug. 12	6?		41	Do.
						Aug. 13	1?		42	Do.
						Aug. 14	2?		43	Do.
						Aug. 18	3?		47	Do.
						Aug. 19	2?		48	Do.

[1] One mature larva was found in the cage Oct. 28

TABLE 1.—*Observations of stages of the bluegrass webworm reared in cages*—Contd.

Cage No.	Date eggs were laid	Date eggs hatched	Egg stage	Date of pupation	Larval stage	Date adults out	Numbers and sex	Pupal stage	Total extent larval and pupal stages	Food
			Days		*Days*			*Days*	*Days*	
15331	?	July 5	?	?	?	Aug. 14	6♂, 1♀	?	40	Bluegrass.
						Aug. 17	2♀		43	Do.
						Aug. 18	2♂, 4♀		44	Do.
12354J	July 3	July 8	5	Aug. 14	37	Aug. 20	1?	6	43	Do.
16176	?	do	?	?	?	Aug. 18	1♀	?	41	Various food, including bluegrass, timothy, crabgrass, Johnson grass, and corn silk.
						Aug. 22	1♂		45	
						Aug. 24	1♀		47	
						Aug. 27	1♂		50	
						Aug. 30	1♂		53	
						Aug. 31	1♂		54	
						Sept. 9	1♂		63	
12354K	July 8	July 13	5	Aug. 19	37	Aug. 27	1?	8	45	
16199	?	July 14	?	?	?	Aug. 24	2♂	?	41	Bluegrass.
						Aug. 25	1♂		42	Timothy.
						Aug. 27	1♂		41	Crabgrass.
						Sept. 2	1♀		50	Do.
						Sept. 5	1♂		53	Do.
16201	?	do	?	Aug. 16	33	Aug. 24	1♀	8	41	Bluegrass.
				Aug. 17	31	Aug. 28	1♂	11	45	Do.
12354M	July 21	July 25	4	?	?	Sept. 7	1?	?	44	Rye.
						Sept. 10	1♀		47	Bluegrass.
						Sept. 13	1♀		50	Do.
16213	?	July 28	?	?	?	Sept. 7	1♀	?	41	Timothy.
						Sept. 8	1♂		42	Corn.
						do	1♂		42	Bluegrass.
						Sept. 10	1♂		44	Timothy.
						Sept. 11	3♀		45	Do.
						Sept. 12	1♂, 1♀		46	Do.
						do	2♂		46	Bluegrass.
						Sept. 14	1♀		48	Timothy.
						do	1♀		48	Bluegrass.
						Sept. 15	2♂, 1♀		49	Timothy.
						Sept. 16	1♀		50	Do.
						do	1♀		50	Crabgrass.
						Sept. 18	1♂		52	Bluegrass.
						Sept. 20	1♀		54	Crabgrass.
						do	2♂		54	Bluegrass.
						do	2♀		54	Corn.
						Sept. 22	1♀		56	Timothy.
						Sept. 26	1♂		60	Bluegrass.
						Sept. 28	2♀		62	Timothy.
						Sept. 29	1♂		63	Do.
						Oct. 5	1♀		69	Corn.
						do	1♀		69	Timothy.
						Oct. 9	1♂, 1♀		73	Bluegrass.
						Oct. 13	1♂		77	Timothy.
						Oct. 17	1♀		81	Crabgrass.
						do	1♀		81	Orchard grass.
						Oct. 19	1♂		83	Do.
						do	1♂, 1♀		83	Bluegrass.
						Nov. 6	1♀		101	Crabgrass.
12354D	July 31	Aug. 5	6	?	?	Sept. 13	1♂	?	39	?
						Sept. 16	3♀		42	?
						Sept. 17	3♂, 2♀		43	?
						Sept. 18	3?		44	?
						Sept. 19	6?		45	?
				Sept. 6	32	do	2?	13	47	?
				do	32	Sept. 21	1?	15	47	Wheat.
				?	?	do	6?	?	47	?
						Sept. 23	1♂, 3♀		49	?
						Sept. 28	1?		54	?
17394	?	Sept. 15	?	?	?	June 13	1♀	?	271	Bluegrass.

It will be noted, for instance, in the series of larvae reared under cage 16102 that, although hatched on the same day, fed on the same food, and kept under exactly the same conditions, the combined larval and pupal life of those individuals reaching maturity ranged from 58 to 105 days. Also under cage 16213 an even greater variation is noted, the range there being from 41 to 101 days, although in that case the variety of food used may have had some influence on the rate of development.

From these data it is easy to see that in the field the generations can not be distinctly separated. Such is, indeed, the case, and from the time the first moths make their appearance in the spring they are usually continuously present in fluctuating numbers. If one hypothetical individual is followed through the season some idea of the possibilities will be obtained. For instance, beginning with the eggs hatching May 14 (cage 16102) it is noted that the first moth emerged July 11. The first eggs laid by this moth would be hatching about July 18. A normal combined larval and pupal period for this season of the year may be as short as 41 days, which would bring the emergence of the first moths of the next generation to August 28. Larvae resulting from this moth would have time to reach a stage suitable for hibernation, but under the most favorable outdoor conditions could not produce another moth. On the other hand, some of the progeny of the same mother (cage 16102), hatching the same day, matured as late as August 27, and one larva remained active on October 28. It is evident, then, that in the latitude of central Tennessee, where this rearing work was done, there may be as many as three generations or as few as one annually, even from the progeny of the same parent.

As far as is known, the winter is passed only in the larval stage.

THE EGG

The eggs of *Crambus teterrellus* are very similar to those of other species of the genus. On the whole, they are slightly larger and more elongate and, although varying with different individuals, could in most cases with reasonable certainty be picked out from a mixed lot of eggs. At the extremes the measurements overlap those of other species.

The eggs, which are perfectly dry and nonadhesive even when first laid, are dropped promiscuously by the moths, either while flying or at rest. A surface beneath a light where the moths have been fluttering is usually thickly strewn with them; but it is a hopeless task to attempt to find them in the open, for they are small and easily concealed among the grass stems and débris.

The duration of the egg stage ranges from five to seven days, the usual time in midsummer being five and, during the cooler portion of the season, six or seven days. The record of four days shown in Table 1 (cage 12354M) was due either to very hot weather just at the time or, more likely, to the fact that the examinations had been made at different hours on succeeding days.

An attempt was made to determine the effect of low temperatures on the duration of the egg stage. A quantity of eggs laid during the night of July 7 was divided into two lots of about 500 eggs each. One lot was left in the laboratory at practically outdoor summer temperature, where they hatched July 13, after a 6-day incubation period. The other lot was kept in a refrigerator, on or near the ice, at a temperature ranging from 42° to 58° F., probably averaging about 50°. These eggs developed slowly, but apparently normally, and on August 17 had begun to show the darkening preliminary to hatching. They were then removed from the cold chamber to the warm room. The next day practically all had hatched, the incubation period having been 41 days. How much longer the eggs could have been held at a lower temperature is not known, but the test reveals a very decided connection between temperature and the length of the incubation period.

It was also found that submerging the eggs in water either retarded or inhibited the development of the embryo. A large number of eggs laid on August 4 were put in a vial and covered with water. Twenty of the eggs were removed each day, dried, and put in a dry vial at room temperature to hatch. Table 2 gives the results in compact form. The asterisk (*) indicates the day of removal from the water, and the figures give the number of eggs hatching each day.

TABLE 2.—*Effect of submergence in water on bluegrass webworm eggs laid August 4*

Lot No.	Date (indicated by asterisk) in August of removal from water of lots of 20 eggs each, and number of eggs hatching, on dates in August indicated																
	5	6	7	9	10	11	12	13	14	16	17	18	19	20	21	23	26
1	*				4	11	1	2									
2		*				2	13	2	1								
3			*				1	12	2								
4				*						14							
5					*						4	1					
6						*					1	1					
7							*				1		1				
8								*				1					
9									*					3	1		
10										*							
11											*					1	1
12												*					

The eggs when first laid are pure white, not "bright salmon pink" as Murtfeldt describes them. After the first day they become cream colored, and, on the third day, pale lemon yellow, which is somewhat intensified, the tinge being a little richer on the fourth day. This color (closest to pale cadmium yellow in Smith's Glossary) is retained until the day before hatching, when the dark heads become visible through the chorion near one end. Two minute black eye spots are visible after the fourth day.

The larva emerges from an irregular hole near, and partly including, the larger end of the egg. The empty shell is waxy or parchmentlike in texture, transparently iridescent or slightly milky in color, and retains its shape.

DESCRIPTION

Cylindrical, the ends bluntly rounded, one end slightly more obtuse than the other. Pure white when laid, changing in four days to a rich yellow which is retained until hatching. The chorion longitudinally ridged with from 16 to 18 acute carinae, which occasionally coalesce, especially toward the extremities. Between these carinae are much smaller, cross carinae, about 25 in the length of the egg, dividing the surface into minute quadrangular depressions. The polar areas are uneven but hardly tuberculate.

Measurements (condensed from the measurements of a large number of eggs): Length, maximum 0.5597 mm., minimum 0.4589 mm., average 0.5100 mm.; width, maximum 0.3355 mm., minimum 0.2798 mm., average 0.3070 mm.

THE LARVA

HABITS

Just before emergence the larva is bent double inside of the egg, with its head pushed tightly against the angle at the larger end. The first rupture of the chorion seems to be caused by sheer pressure, and then the opening is trimmed and enlarged with the mandibles. The larva of this species when first emerged is of a uniform pale-yellow color with a slight dusky tinge, the head shining black, and the cervical plate deep fuscous. The head is larger in diameter than the body, which tapers caudad.

The larvae start off at once and travel rapidly until they find a suitable hiding place or become exhausted in the attempt. They spin a thread as they go and if dislodged readily suspend themselves. A vial containing a number of larvae is soon lined with a fabric so delicate as to resemble a coat of white paint.

The larvae are negatively phototropic and positively geotropic, and when given the opportunity soon conceal themselves among the leaf bases of a grass plant. They do not prefer the trough of a leaf in which to begin feeding, but begin at once to construct retreats by webbing together the sand particles of the surface of the earth. Closely opposed leaves are often webbed together to form a tube, within which the larva lives and feeds. More or less fine green excrement is placed in this webbing, and the protective net is soon opaque. If disturbed, the larva quickly seeks the most opaque portion of its burrow, and, if further harassed, coils itself into a tight, flat helix.

At first only the surface tissue of the leaf is eaten, and the veins and tougher membranes are left, but as the larvae become larger they notch the leaves near the base and finally cut them off completely. Larvae placed on a small wheat plant were unable to feed satisfactorily at the base of the plant, and ensconced themselves on the leaves, where their feeding soon became apparent as small whitish pits on the upper surface, each pit roofed by a delicate web of silk bearing particles of excrement in its meshes. The larvae remained under these webs until they became too large for concealment. The area skeletonized by each larva during the first instar was about 5 mm. long by 0.5 mm. wide.

When the larvae become too large to conceal themselves longer in their first retreats among the leaf bases, they construct other, larger ones, radiating from the plant along the surface of the ground. The retreats made by the larvae of this species are not so carefully built as those of most of the other species, but look like haphazard affairs. Instead of being complete tubes lined with silk, they are merely tunnels roofed with sand and earth particles held together with silk, and often with the bare earth for a floor. Murtfeldt (*14, p. 53*) notes that the quantity of web tubing produced was extensive, out of all proportion to the size of the larvae. There are often several radiating passages, each from 10 to 40 mm. long, within any of which the inmate may take refuge when danger threatens. These passages end close to the base of the plant, and it is evident from their position that the larvae feed for the most part directly on the plant. Occasionally, when in the proper position, a leaf may be cut off at the base and drawn into the mouth of the burrow so that the larva can feed without exposure. The outlying ends of these shelters are packed with green granular excrement, and as they become crowded or too small, others are constructed and filled in turn. In the field the sight of a tuft of grass with many of its leaves cut cleanly off close to the base and the dry green frass from it seen when the surface of the earth is disturbed are evidence of the near-by or recent presence of one of these larvae.

In addition to these flimsy feeding burrows at the surface there is often found a much more carefully constructed silk-lined tube, from 10 to 30 mm. long, standing perpendicularly in the earth. It is smoothly lined with silk, and when removed from the earth feels rather stiff and firm to the touch. The upper end is closed by an ingenious device consisting of two lips of unequal size, constructed of silk and covered outwardly with sand or particles of earth, affording almost perfect concealment. The larger lip is hood shaped; the smaller tightly closes the opening, or may be left agape at the will of the occupant. This safer retreat is built later in life as the larva approaches maturity. It seems to serve as a place of more permanent refuge, and to be resorted to during ecdysis and during the daytime, when the surface shelters become too hot and dry for comfort. Leaves are sometimes drawn into these perpendicular burrows, but they are kept clean and free from excrement.

MOLTING

The act of molting was several times observed, and as the process was exactly similar in each instance the notes describing the molt at the end of the first instar are quoted herewith:

> The new head, very pale except for the black spots which show plainly on the genae, can be seen between the old head and the fuscous cervical plate. After lying quietly beneath the sheltering web for some hours, the larva began a twisting motion. After a little gentle writhing and twisting, the skin ruptured transversely just back of the old head, leaving it free of skin. The rupture completely encircled the body along the caudal margin of the head. The skin was so transparent and diaphanous that it was difficult to see the exact edge, but its position could be determined by the location of the cervical plate, which remained with this skin and moved backward with it. The skin did not further rupture, and its presence was not apparent until it began to wrinkle up on the last two or three segments. As the open end passed caudad the body of the larva was constricted as by a belt, and often serveral motions were necessary to force the skin past one segment. As it passed, the setae, which had lain pressed to the body under the old skin, sprang erect. After the center of the body was passed the skin moved more rapidly, a segment at a time. The cast skin was dingy, flattened against the leaf, and terminated at the cephalic end by the cervical plate. There was no rupture in it other than the one around the neck next the head. While the skin was being cast, the head and anterior portion of the body remained motionless, the old head still in place and inclosing the mouth parts and ventral portion of the new head. When the skin was disposed of, the old head was quickly loosened by a wiping motion of the head against the leaf surface. The entire operation did not occupy more than 15 minutes. The newly molted larva is pale with a pinkish tinge to the body, head white or transparent, mouth parts yellow, the lateral spots on the genae jet black. The internal muscles of the head with their converging fibers show plainly through the epicranium. The cervical plate is transparent, and the caudal segments of the body are very pale. In a couple of hours the head and cervical plate have darkened, and the body has assumed a dusky hue.

NUMBER OF INSTARS

The number of instars through which larvae of this species pass before pupation varies widely, more so than in any other of the species studied. Of 14 individuals whose records are at hand, two passed through 7 instairs, six through 8, five through 9, and one through 10 instars, prior to pupation. This last number does not by any means exhaust the possibilities, for several larvae far exceeded this number; however, they appeared to be abnormal and finally died either as larvae or while attempting to pupate. As is clearly shown in Table 4, which gives instar measurements, larvae passing the eighth instar did not increase in size, but merely existed, feeding slowly and being apparently in perfect health. The writer has records showing that some of these larvae reached the twentieth instar before finally succumbing.

Another interesting observation was made several times in the course of the work on this species. For some reason a larva failing to molt normally would emerge from that trying experience with mandibles so deformed that feeding was impossible. Instead of dying, it would lie about the box several days, and at about the normal time molt again, perhaps bringing its mouth parts back into normal condition, without having fed in the meantime. In a few instances the deformed condition of the mouth parts persisted through two and even three instars; but the larva survived, and when it finally became normal it resumed feeding as if nothing had happened.

In the duration of the various instars this species also shows somewhat more variation than is usual in the genus. Forty larvae in cage 15285, and 30 in cage 15311, were kept under constant observation to determine the length of the various instars. The larvae of the former series hatched June 12, and those of the latter June 22. When the records for each series were tabulated they were found to be in such close agreement that they were combined in Table 3.

TABLE 3.—*Duration of instars and of larval and pupal stages of larvae reared under cages Nos. 15285 and 15311. (Hatching of June 12 and June 22)*

Instar	Duration: Maximum	Duration: Minimum	Duration: Average	Number averaged
	Days	*Days*	*Days*	
1	7	4	5.4	70
2	5	2	3.4	56
3	5	2	3.0	47
4	8	2	3.9	39
5	7	2	4.1	32
6	10	2	4.7	27
7	13	2	5.3	20
Prepupal 7	11	7	9.0	2
Prepupal 8	12	4	6.5	12
Prepupal 8	18	6	10.3	6
Prepupal 9	9	4	7.0	3
Prepupal 9	11	7	9.0	5
Prepupal 10	9	9	9.0	1

Summary

Stage	Duration: Maximum	Duration: Minimum	Duration: Average	Number averaged
	Days	*Days*	*Days*	
Larval	60	32	43.1	11
Pupal, male	13	7	8.8	5
Pupal, female	8	5	6.7	6
Combined larval and pupal	73	41	53.1	11

It can be seen at a glance that the range for each of the instars and for the total larval life is unusually great. The instar preceding pupation, whichever one it may be, is always the longest of any in the life of that individual. For that reason, it would not be accurate to average them with those of other larvae with a different number of instars; they are therefore listed separately as "prepupal" instars.

FOOD PLANTS

These larvae seem not at all particular about their food provided it is grass. Larvae were reared wholly or in part on Kentucky bluegrass (*Poa pratensis*), wheat, rye, timothy, crabgrass (*Syntherisma sanguinalis*), Johnson grass (*Sorghum halepense*), orchard grass (*Dactylis glomerata*), pigeon grass (*Setaria glauca*), and corn, both leaves and fresh silk. Of the foregoing food plants Kentucky bluegrass is by far the one most commonly fed upon. Young larvae refused to eat leaves of Johnson grass, but later fed on them readily. Some larvae were given moss of several species, and, although they nibbled it slightly, they showed decided preference for grass of any sort. Cowpea leaves were offered and refused. There are doubtless many species of grass, in addition to the above-named kinds, on which the larvae will feed and thrive.

DESCRIPTION OF INSTARS

The ability of the larvae to grow and mature on starvation rations, if necessary, results in a corresponding variation in the length of the body and width of the head of the larvae, especially in the later instars. Because of this overlapping it is much more difficult to say with certainty to which instar a larva of this species belongs than is the case with many of the other species studied. It is probable that seven or eight is the normal number of instars with these larvae, as up to that number there is a fairly constant and regular increase in size. The variation in size of the larvae in the different instars is shown in Table 4.

TABLE 4.—*Larval measurements of the bluegrass webworm*

Instar [1]	Number measured	Width of head			Length of body
		Maximum	Minimum	Average	
		Mm.	*Mm.*	*Mm.*	*Mm.*
1	(2)	0.219	0.194	0.207	1–2
2	9	.317	.247	.290	2–3
3	21	.466	.373	.406	2.5–3.5
4	21	.653	.466	.560	3–5
5	9	.933	.653	.793	5–7
6	10	1.026	.746	.914	6–11
7	13	1.213	.932	1.059	7–12
8	11	1.399	1.026	1.203	9–13
9	5	1.212	1.119	1.166	(3)
10	4	1.260	1.166	1.212	(3)
11	3	1.260	1.212	1.235	(3)

[1] A single larva measured through additional instars showed widths of head as follows: 12, 1.212 mm.; 13, 1.212 mm.; 14, 1.212 mm.; 18, 1.399 mm.; 19, 1.399 mm.
[2] Many.
[3] Not measured.

Instar 1. Head deep fuscous to black, cervical plate fuscous, slightly paler than head. Body pale yellow before feeding, almost transparent, especially caudad, and tapering evenly back from cervical plate to the rather narrow cauda. The ingested chorion appears as a dull brown spot moving gradually through the body. After feeding, the body becomes cylindrical and dusky green in color from the intestinal contents. The head and body bear slender pale hairs which arise from minute clear areas in the chitin. The pinacula are concolorous with the body and inconspicuous. Under higher magnification the skin appears minutely granular and is covered very lightly with a saffron overcolor.

For the arrangement of the pinacula and setae in the later instars see Figure 2, E.

Instar 2. Head dark fuscous to black, mouth parts a little paler. Cervical plate dark fuscous, transverse, about twice as long as wide, rounded laterad and with a round dark spot in the center of each extremity. Body color pale yellow

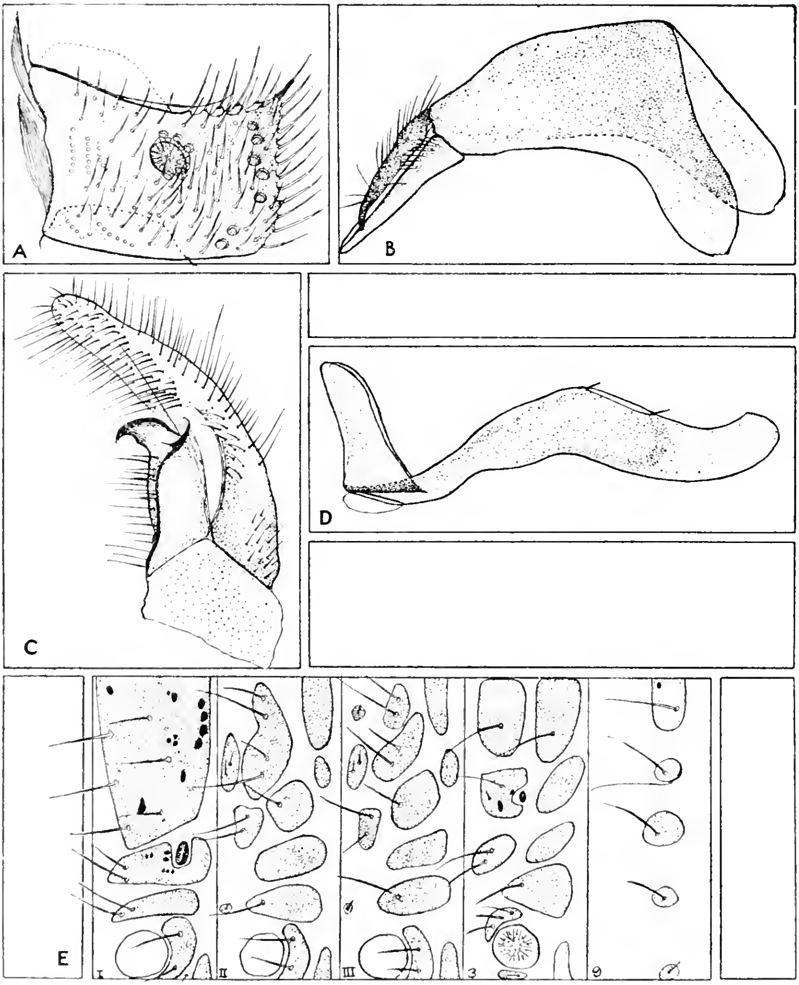

FIGURE 2.—The bluegrass webworm (*Crambus teterrellus*): A, Antennal segment of male moth; B, tegumen of male genitalia; C, clasp of male genitalia; D, aedoeagus of male genitalia, showing anellus in position; E, setal map of mature larva, showing arrangement of pinacula and setae on the first, second, and third thoracic and the third and ninth abdominal segments

overlaid with rufous, giving the whole larva a brownish-red appearance, the overcolor more or less broken and mottled at sutures and along the sides of the body. The ingested food adds a greenish tinge and the dorsal vessel shows a narrow dark line. Segments of thorax and abdomen well marked, those of the former each bearing a transverse row of six small pinacula and those of the latter with six pinacula on the anterior lobe and a single more widely spaced pair on the posterior lobe. The caudal segment bears a dorsal subquadrate setigerous plate. Skin of thorax and abdomen finely granular or punctate.

Instar 3. Head yellowish brown, frons paler than rest and outlined with a narrow dark line marking the vertical suture, emarginate at vertex and with several pale hairs on face. Cervical plate brown, paler than head and with a faintly darker line on each side of median line and a small dark spot in the center of each extremity. Skin of thorax and abdomen minutely punctate, amber yellow overlaid with a rufous tinge. Pinacula nearly concolorous with body, but apparent because of their smooth texture. The dorsal vessel appears darker, and the pinacula are slightly darker around the margin. Caudal plate a little darker than body.

Instar 4. Head dusky yellow, usually of uniform color, but in some specimens clouded with indistinct darker areas; frons paler. Cervical plate dusky yellow with a darker spot near the middle of each extremity. Skin of body yellowish, but rather heavily overlaid with a rufous or maroon overcolor which gives the entire body a liver-colored aspect. The corneous spots or pinacula are concolorous with the body but transmit the greenish color of the body contents more readily than the skin, and therefore appear dusky greenish. The setae arise from small black rings. Caudal plate pale with dark areas surrounding the setae. Except for the color of the head the larva at this stage much resembles that of *Crambus trisectus*. The pale unmarked head of *teterrellus* differentiates the two.

Instar 5. Head dusky yellow with an indistinct pattern of darker yellowish-brown markings, frons little paler, mouth parts dark. Cervical plate dusky yellow, mottled with darker spots, slightly darker than head. Body purplish, with spiracles, and cicatrices on pedal segments, black. Pinacula concolorous with skin and not conspicuous except the small dark spots surrounding each seta. Caudal plate pale with blackish spots.

FIGURE 3.—Pupa of the bluegrass webworm (*Crambus teterrellus*). × 4

Instar 6. Head dusky yellow with an indefinite pattern of darker areas. Cervical plate dusky yellow, slightly darker than body color. Body color dusky yellow tinged with green by the body contents, skin dull, finely granular. The purplish overcolor has largely been lost, and the larva at this stage begins to develop the body color and arrangement of pinacula which characterize it. Pinacula concolorous with skin but finely rugose and faintly shining, fairly well defined, those on thorax and on lateral aspect of abdomen darker than skin and more prominent than those on dorsum of abdomen; those on thorax rather small and well separated. The anterior dorsal pair of pinacula on the abdominal segments are large, subquadrate, and with their median margins straight and parallel, the posterior dorsal pair confluent into a transverse band except on posterior segments. The black cicatrices on pedal segments larger than spiracles and conspicuous. Caudal plate pale with blackish markings.

Instar 7. The description of this instar agrees in almost every particular with that of the one preceding. The anterior dorsal pinacula have become even larger and more closely opposed than before, often fusing into a single, broad, transverse band with only slight indication of a median division. The characteristics of this larva are fully developed, the yellow head in some specimens faintly clouded with darker markings, the dusky yellow body with numerous and very large pinacula. Apparently the development of these corneous spots reaches its climax in this species, for all that appear on any species are present on this and in their largest size. The thoracic segments are almost fully covered and the abdominal only slightly less so. The combination of the yellow head and the large dorsal pinacula, especially the large subquadrate closely opposed anterior dorsal pair on the abdominal segments, differentiates this species from any others studied.

THE PUPA

There is nothing especially distinctive about the pupal stage of this species. (Fig. 3.) When the larva has completed its growth it abandons its feeding burrow and constructs a cell in the earth near by, usually within an inch or two of the plant upon which it has been feeding. This cell is lined loosely with gray silk and forms the cocoon. It is oval, with the larger end down, stands vertically in the earth, or nearly so, and, with the adhering earth, is about 14 mm. long and 6 mm. wide. It is not substantially made and rarely retains its shape when dug up. It is built so near the surface that no neck or extension is needed to allow the moth to escape. In this cocoon the pupa is formed with the head uppermost.

The length of the pupal stage ranges from 5 to 15 days, the usual period in midsummer being 7 or 8 days. Although somewhat longer in the cool weather of spring and fall, the extent to which this prolongation is possible seems quite limited, and pupae held at low temperatures for any period in excess of the maximum given in Table 3 invariably died. A detailed description of the pupa is nearly a repetition of those given for other species, except that the caudal process or cremaster is straighter and somewhat more distinct than with the others. It is narrow, sharply excavated beneath, and straight above.

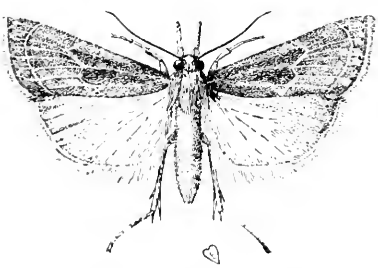

FIGURE 4.—Moth of the bluegrass webworm. × 3.

When the moth (fig. 4) emerges the empty pupal skin remains wholly within the cocoon.

DESCRIPTION

Length 8 to 10 mm.; width 2.5 mm. General color amber yellow, each suture marked with a fine maroon line, thus making the exact shape of the various organs easily distinguishable. Entirely glabrous except for the very minute setae on cremaster.

Vertex slightly bilobed, eyes slightly produced, labrum at base three times width at tip, femur of the prothoracic legs apparent for a short distance between the maxillae, and the tarsi of the prothoracic legs visible for a short distance beyond the maxillae and between the tarsi of the metathoracic legs. On the venter, only abdominal segments 4 to 9 visible, no suture between the eighth and ninth. On the dorsum spiracles are visible on the second to seventh segments, those on 2 and 3 lying close to the margin of the hind wings, which are narrowly exposed beyond the posterior margins of the anterior pair. Cremaster a rounded process, flattened slightly dorsoventrad, bearing at its tip two widely separated diverging minute setae and dorsocephalad of these two more still smaller. At the base of the cremaster, dorsad on each side is a short, deep, slightly curved groove.

THE MOTH

HABITS

During the season of their abundance the moths are found in almost every possible location, but they are most numerous in meadows, in pastures, and on waste land. They are free fliers and evidently travel considerable distances, judging from the numbers that often gather at lights. During the day they are not often seen unless disturbed, but on cloudy days and late in the afternoon, toward dusk, they are easily flushed and fly freely. As a resting place they prefer broad-leafed plants to grass, and almost invariably alight on ironweed, goldenrod, ragweed, etc., when such plants are available. They often alight on the upper surface of the leaves, but immediately scuttle beneath and come to rest with the head pressed closely to the surface and the abdomen and wings elevated at an angle of 25°. This characteristic posture, and the white scales on the top of the head, visible at a considerable distance, easily distinguish this species from any others with which it may be associated in the field. The moths vary widely in size, the females invariably averaging larger than the males. Some of the males, especially those maturing during dry periods in midsummer, are very small, scarcely half the size of the largest males produced at more favorable seasons. Aside from their smaller size, the males are easily distinguished from the females by the shorter and broader antennae, those of the females being setaceous.

REACTION TO LIGHT

Throughout the region of its occurrence this species is more strongly attracted to light than any of its congeners, with the possible exception of *Crambus trisectus* Walk. When weather conditions are favorable the moths come to lighted house windows and porch lights by hundreds and sometimes literally by thousands, at times interfering seriously with the comfort of those who wish to use their porches. In 1915, at Nashville, Tenn., over 7,000 moths were collected at the windows of one small building during one night.

Because of its abundance and strong positively phototropic tendencies, the species provided a good subject for the study of this characteristic, and also of the possibilities of using trap lights as a means of control of this and related species. During the summer of 1915, at Nashville, Tenn., Mr. Cartwright and the writer made a series of all-night collections of these moths at light. The collections of each 15-minute period were kept separate, and the sex of each moth was determined. The detailed results have been given in a previous paper (*2*). The conclusion arrived at was that the great majority of the female moths came to light early in the evening, coming in greatest numbers about 30 minutes after it became dark enough for the light to attract. The males, on the other hand, came in very small numbers early in the night but reached their maximum flight between 11.15 p. m. and 1 a. m. At 10 p. m. only 15 per cent of the total number of males taken had appeared, whereas 60 per cent of the total number of females taken had come.

Although it seems certain that meteorological conditions, or certain combinations of them, have great influence on the number of moths coming to light at any given time, the writer was unsuccessful in determining the deciding factor. It was repeatedly noted that of two nights under very similar weather conditions there might be on one a profuse flight of moths whereas on the other they would be very scarce. Much work remains to be done along this line, as well as on the relative attractiveness of different colors and kinds of light.

FEEDING

Observations in the field and experimental evidence unite to show that in nature the moths do not feed except possibly on water in the form of dew or raindrops. In numerous experiments, moths, both males and females, were kept in cages, dry, with water alone, and with diluted honey available as food. In every case those kept in dry vials or boxes died first and, if females, laid the fewest eggs. Those offered dilute honey came next, and those with water available lived longest and laid the greatest number of eggs. Aside from an occasional individual accidentally present, the writer has never taken these moths at sugar or other bait put out as an insect attractant, and they are not attracted to flowers. Those kept in boxes with dilute honey available did feed, but apparently as much for the sake of moisture as for the honey, and the addition of the latter resulted in no increase either of longevity or of fecundity.

FECUNDITY

The ovary consists of 8 ovarioles arranged in 2 groups of 4 each, opening finally into the common oviduct. The tubes or ovarioles are so arranged in the abdomen that each is divided into 4 sections by 3 bends. In a freshly emerged moth the first 2 sections contain large, white eggs, fully matured and ready for oviposition, there being about 5 to a section. The third contains about 10 partly developed ova of approximately half the size of those in the first 2 sections. They contain some opaque white matter, but are partly transparent. The last section is the narrow extremity of the tube and contains about 15 or more very small, transparent egg cells, gradually decreasing in size until they merge into the transparent fiber of protoplasm which terminates the tube. There are thus about 35 discernible eggs in various stages of development in each ovariole, or about 280 in the entire ovary. The ovary and surrounding space in the abdomen are packed with small, white fat masses. The quantity of this fat varies greatly in different moths and is apparently dependent on the abundance and quality of the food supply during the larval life. A study of many dissections of fresh and spent moths shows that the fat, the more immature ova, and even the ovarioles themselves, and other organs, are gradually absorbed as oviposition progresses until finally the eggs are all matured or absorbed, and the abdomen is practically empty. When this point is reached oviposition necessarily ceases, and the vitality of the moth is so completely exhausted that death soon ensues.

The eggs of all the species of Crambus vary little in size, and the number which one female can produce seems to be proportional to her own size. As *C. teterrellus* is one of the smaller species, and the eggs are probably larger than the average for the group, this species lays proportionately fewer eggs than do the larger species. The egg-laying records of several hundred moths captured in the field and at light are available, as are also those of many reared individuals. The largest number of eggs recorded from a single moth of this species is 564. This moth reached probably about the extreme limit for the species, it being the only one that produced more than 500. Three others produced over 400 each and 10 others over 300. These records were all made by moths collected in the field or at light and kept confined individually in tin boxes with a wad of wet cotton. A few of those given dilute honey laid more than 300 eggs each. Of 350 moths taken in the field and kept in dry boxes or vials, none laid as many as 300 eggs, and only 23 laid more than 200. Only 18 of this lot laid no eggs at all.

The average number of eggs obtained from the 350 moths mentioned above, collected in the field and kept in dry containers, was 79. The average obtained from 104 moths collected in the field and kept in boxes with wet cotton was 166, which is still below the number actually produced, because many of the moths doubtless had disposed of a considerable number before capture. Judging from all the data at hand, the number of eggs produced by the average moth of this species under normal conditions is probably between 200 and 250.

The eggs are laid during a period beginning at about 4 p. m. and reaching the maximum rate of production shortly after dark. After midnight only a few eggs are laid, and with the coming of dawn oviposition ceases altogether, not to begin again until afternoon. The writer has noted many times that even though moths were confined in light-tight tin boxes and kept in a dark place, they could not be induced to oviposit until the proper time of day arrived, when their behavior in this regard would correspond exactly with that of moths in the open. The egg-laying mechanism is apparently quite independent of the will of the moth, and is set in operation by some factor connected with the approach of evening and independent of the waning light and declining temperature. Further evidence of this is afforded by the observation that if female moths about the light are disabled by a tap of the finger on the thorax sufficient eventually to kill them, oviposition continues without cessation often for a half hour or more. Some moths treated in this manner laid nearly 100 eggs each before all motion ceased.

The number of eggs laid in any one day varies greatly. In several instances over 200 have been laid by one moth within 24 hours, and 100 or more is a common record. The records of two reared moths given below indicate what occurs when moths are kept under conditions as nearly natural as possible. One moth which emerged August 3 laid her first eggs on August 7 and daily thereafter, with one exception, the entire count being as follows: 5, 4, 3, 5, 8, 14, 10, 9, 11, 60, 0, 5, 13, 9, and died on August 21, with a life period of 18 days, having laid a total of 156 eggs. Dissection after death showed 5 mature eggs still in the oviduct. Another, emerging August 7, lived 29 days, laying during that time 269 eggs, beginning August 10 as follows: 5, 5, 8, 9, 12, 11, 21, 3, 21, 31, 56, 21, 11, 17, 16, 11, 7, 4. She lived until September 5, but produced no eggs after August 27, and when dissected her abdomen was practically empty.

MATING

The mating habits of these moths have been observed on several different occasions, but always under similar conditions. Quotations from notes made on September 12, 1914, will best describe the action.

On the screen and windows of the laboratory these moths were observed mating this evening. The screens were swarming with the moths attracted to the light. The amorous males flutter up the screen, half walking and half flying. When they approach another moth the genitalia are suddenly extruded, and the mass of long slender scales inside the outer sheath opens out, making the end of the abdomen appear as bushy as a small chrysanthemum. The abdomen is extended and turned outward and forward so the genital organs face forward. Sometimes the abdomen is bent so far around that the movements of the legs on that side are interfered with, and the moth in walking stumbles over its own body. The moth approached, either male or female, is disturbed and moves forward a few steps. The male flutters after it and, while headed in the same direction as its prospective mate, reaches under the wings and searches for the tip of the other's abdomen. If this one happens to be a female and in a receptive mood the union is soon made, and the male at once drops his wings over those of the female and swings around until he is headed in the opposite direction from his mate. The female, being the larger, is able to drag the male about at will. The males in search of mates frequently follow and seek to unite with other males. There seems to be no selection practiced. As soon as the union is made and the moths have assumed their normal position, they become motionless and remain so until the act is complete, or nearly so. The female gives the first indication of uneasiness, vibrating the wings and twisting the abdomen. Usually this occurs two or three times, for a moment each, until finally the moths separate. After the pair separates each remains more or less quiet for some time, the male appearing weakened.

Many of the males die within from 12 to 24 hours after mating. The mating seems to take place rather spasmodically and only when the moths are fairly abundant on the window. For some time none will mate, and then in a minute or two several couples will form. Mating does not begin until the evening is well advanced. One night when especially careful watch was made the first pair was noted at 9 o'clock. This is perhaps explained by the fact that the males do not make their appearance in any numbers until about that time. If no moths are removed, but all are allowed to accumulate on the window, by midnight or later the numbers of the two sexes are, approximately equal. In the case of 23 couples under observation the duration of the union ranged from 12 minutes to 2 hours and 20 minutes, with an average of 66 minutes.

It seems probable that each female mates but once, and this may also apply to the males. Females confined in a cage with males for only a short time after emergence, and then isolated, lay fertile eggs for several days, apparently until their quota is exhausted. Also, it is evident that in nature mating takes places very shortly after the emergence of the moth; for among the hundreds of females collected at light and in the field, very seldom was one found whose eggs were not fertile.

LONGEVITY

It is impossible to determine exactly how long the moths live in their natural surroundings. Several hundred moths, some reared, but most of them collected in the field and at light, were kept under various conditions to determine as closely as possible their natural span of life. This undoubtedly varies greatly. Individuals passing their larval life in situations where food was suitable and abundant emerge as larger moths and with much greater reserve stores of fat than those partially starved during their larval lives. Most of the moths studied were kept in one of the following ways: In dry vials or tin boxes; in tin boxes or open cages with a pellet of cotton saturated with clear water; or in similar boxes or cages with the cotton saturated with diluted honey. In all three situations the females lived appreciably longer than the males, the average difference being a little more than one day. Those kept within reach of water lived longest, and the difference between the dry and the honey-fed moths was so slight as to prove conclusively that the nutritive value of the honey was of no benefit. The longest life of any individual moth was 29 days. This individual was a female which emerged in a breeding box August 7, and was fed with dilute honey. In an open cage provided with clear water one female lived 28 days, another 23, and a male lived 25 days. The longest life recorded for a moth without moisture was 19 days—in this case a female that was fed abundantly as a larva and emerged in one of the tin-box breeding cages. No moth taken in the field and given honey lived more than 12 days after capture.

Table 5 condenses all the writer's records on this point in a form suitable for comparison. From observations in the field it is surmised that under conditions entirely normal the life of a moth is from 7 to 10 days.

TABLE 5.—*Number of moths of Crambus teterrellus (of a total of 1,471 observed, of both sexes), living in cages the number of days specified, under three conditions of nourishment—dry vials or boxes, with clear water, or with honey*

Length of life in cage (days)	Number of moths of sex indicated living days specified under given conditions of nourishment					
	In dry inclosure		With water		With honey	
	Male	Female	Male	Female	Male	Female
1	4	8	2	3		3
2	107	94	32	39	29	40
3	97	80	20	38	19	31
4	83	110	9	40	10	29
5	50	54	12	22	8	23
6	22	43	12	21	2	7
7	6	35	7	18	2	10
8	4	21	7	19	1	11
9	3	11	6	8		5
10	1	17	4	13	2	5
11		2	4	5		1
12		5	4	2	1	1
13		2		6		
14			2	4		
15			2	1		
16		2	1	3		
19		1				
23				1		
25			1			
28				1		
Total	377	485	125	244	74	166
Total days lived in cage	1,334	2,245	684	1,398	261	725
Average life in cage, days	3.54	4.63	5.47	5.73	3.53	4.37

DESCRIPTION

Wing expanse 15 to 21 mm. Palpi and head above white; palpi beneath, thorax, and abdomen pale cinereous. (Fig. 4.) Fore wing cinereous with a tinge of luteous more pronounced in some specimens than in others, basal half darker and with numerous plumbeous or blackish scales especially in the cell and just below. Median line orange, running from just beyond the middle of the anterior margin to the tip of the cell, thence to the middle of the anal margin with an outward angle at the fold. Subterminal line orange, edged outwardly with white, running from a point midway between the median line and the tip of the wing to near the basal angle, with an obtuse angle a little above the middle. Between the median and subterminal lines the intervenular spaces are more or less prominently marked with orange scales and edged with black, veins lined with white. Terminal line of seven black intervenular dots, the spaces between it and the subterminal line covered with white scales tipped with black, giving this area a salt-and-pepper appearance very characteristic of this species. Fringe cinereous with a golden tinge. Hind wings uniformly pale cinereous with white fringes. Fore wings beneath uniformly dark cinereous, with small darker terminal intervenular dots. Hind wings beneath paler than the fore wings, with a narrow brown marginal line. Antennae of female setaceous, of the male shorter and broadened, each segment extended laterally so as to give it the general shape of an ax head. Near the center on both the upper and lower faces of the segment (fig. 2, A) is a compound sensorium consisting of one large sensorium closely surrounded by a varying number of others similar in size and structure to those found on other species and elsewhere on the same segments in *Crambus teterrellus*.

On the more highly developed segments near the middle of the antennae the group may be composed of as many as 10, or even more, of the smaller sensoria. Toward either extremity the number decreases until only two or three occur in each group. Under low magnification this compound sensorium shows merely as a distinct dark spot, and Felt (*7, pl. VI, fig. 7a*) has so represented it. No compound sensorium has been met with on any other species examined.

Genitalia; male: Tegumen (fig. 2, B) with limbs broad and short, rounded distad, body long and broad, uncus rather slender, setigerous above and at base and along margins, terminating in a long, strong, gently curved tooth which lacks only a little of reaching the tip of the gnathos; gnathos also rather slender, naked, tapering evenly from the base to a narrow truncate apex. Harpes (fig. 2, C) somewhat convolute at base, the free costa much shortened and truncate at tip, with the angles produced into short recurved hooks, cucullus rather narrow, fingerlike, and densely hairy above. Sacculus not sharply differentiated, but meeting the base of the cucullus with a rounded, more heavily chitinized lobe bearing a group of short, stout spines. Vinculum weakly chitinized and rather large but not sharply differentiated. Aedoeagus (fig. 2, D) not heavily chitinized, slender and tapering toward each end. Cephalic end evenly rounded and produced cephalad of the dorsal opening for the penis, caudal end obliquely truncate with the opening for the egress of the penis ventrad. From the caudal extremity arise two large flat chitinous processes curving outward and upward in much the shape of a horseshoe and, so far as is known, entirely unique with this species. There are no cornuti. The anellus (fig. 2, C.) is a definite scutate chitinous plate, accurately filling the opening between the bases of the harpes and the tegumen, and with an elliptic hole through which the aedoeagus passes.

Female: Anal plate much narrower than long, narrowly rectangular, with the apex only slightly produced.

Although none of the moths are conspicuously marked, the wing pattern in some is much more distinct than in others. The general color varies from a light fawn to a dark earthy brown. The marking of the subterminal area is characteristic of this species, and is sufficient to make certain determination of specimens possible, even if no other portion is available. As they become worn, the moths of both sexes appear lighter in color, but, either because they live longer or are more active, the females become badly rubbed much more commonly than the males. The points which conspicuously differentiate this species from its congeners are the characteristic mottling of the subterminal area on the wing, the white scales on the top of the head, and the resting position with the body held at an angle of 25° with the surface. Furthermore, the compound sensoria on the antennae and the peculiar processes on the extremity of the aedoeagus seem to be wholly unique with this species.

PARASITES AND PREDACIOUS ENEMIES

Because of the failure, so far, to devise any satisfactory method of collecting the larvae of these moths in quantity from their burrows, very few have been reared except those hatched from eggs in the laboratory. It is due to this fact, rather than to their scarcity, that very few parasites have been reared from *Crambus teterrellus*. There are without doubt many more species than have been recorded that attack the host, not only of internal parasites but also of predacious enemies and fungous and bacterial diseases.

PARASITES

In a breeding jar containing larvae of various stages collected from the lawn, Murtfeldt (*14, p. 54*) found "the remains of two or three hymenopterous parasites and four cocoons of the characteristic form, color, and structure of Meteorus, closely resembling those of *M.*

hyphantriae." These parasites seem never to have been definitely determined, and no others of the kind have been recorded. A larva of *Crambus teterrellus* found feeding on a plant of orchard grass (*Dactylis glomeratus*) at Nashville, Tenn., May 11, 1914, had on May 28 constructed a pupal case in the earth. In this pupal case was found the empty skin of the host and a brown cocoon of a parasite. The cocoon was 12 mm. long and 4 mm. in diameter, cylindrical with rounded ends, and lined inside with white silk. The cocoon was loosely spun, so that the body of its maker could be seen within, but not with sufficient distinctness to tell whether it was a larva or a pupa. The adult parasite emerged June 8, and was determined by A. B. Gahan as *Cymodusa mississippiensis* Ashm.

PREDACIOUS ENEMIES

Attempts were repeatedly made to interest ants in the eggs of this species, it being supposed that as the eggs are dropped promiscuously in the grass ants must often run across them. Only one such attempt was successful, and in this instance eggs dropped near the entrance to their burrow were eagerly seized and carried inside by small brown ants, a species of Pheidole. An unsuccessful endeavor was made to find what became of the eggs. Other ants paid no attention whatever to them.

Robber flies, determined by Aldrich as *Erax aestuans* L., have many times been seen capturing moths of this and other species of Crambus. The flies wait at some exposed point and, when a moth flies near enough, dart out and seize it, returning to their perch to consume it at their leisure.

In one instance a larva of *Chauliognathus pennsylvanicus* DeG. was captured, partly within a pupal case, also within which was found the partially consumed body of a larva of *Crambus teterrellus*.

SUGGESTED CONTROL MEASURES

No practical methods of control have been devised for this or other species of Crambus larvae working in sod lands. Attempts to kill them with poisoned-bran bait in various combinations seemed fruitless. It is possible that if the bran bait can be mixed with some substance which is a strong attractant for the larvae they can be reached. Such a substance has been suggested in nitrobenzene, first used for this purpose by A. C. Morgan at Clarksville, Tenn., for the control of the larvae of *Crambus caliginosellus* Clem. attacking young tobacco plants. Since this information has been available no opportunity has presented itself to test the method with other species, but it is well worth the attempt.

Although it would probably not be feasible to operate light traps solely for the control of this insect, studies of its night habits indicate that such lights operated from dusk until midnight would capture large numbers of gravid female moths and prevent the deposition of vast numbers of eggs.

SUMMARY

The bluegrass webworm is so called because it is most abundant in the sections of the country where bluegrass is a dominant plant species and because it is found feeding principally upon it. The adult is a small grayish moth.

It was described in 1821, but has attracted very slight attention from entomologists, and its complete bibliography is very short.

It is widely distributed in the eastern and the southeastern parts of the United States, and in several States is probably the most abundant species of moth.

Its economic importance is undoubted. In ordinary seasons it is a cause of serious depletion of pastures, and in dry years may be the real cause for the complete killing out of sod in pastures and lawns.

Under ordinary conditions there are three broods each year, but individuals vary so greatly in their rate of growth that progeny of a single moth may cover one, two, or three generations in the same season. The principal flights of the moths occur in May, July, and September.

The egg is similar to the eggs of other species of the genus, but averages slightly larger. The larvae construct flimsy tubes of silk and earth particles, in which they remain during the day, emerging at night to feed. The normal number of instars for this species seems to be eight, although there is great variation. As many as 20 instars have been observed in the case of some specimens, but in such instances there was no increase in size after the eighth instar.

Kentucky bluegrass is by far the most commonly infested food plant although other grasses are eaten readily. No food plants other than grasses are known to be eaten.

The pupae are formed in loosely made pupal cases constructed separately from, but near, the feeding burrow. The moths become active about dusk, and are attracted to lights in large numbers. They do not feed, except possibly on water.

Eggs are dropped promiscuously. The average number produced by one moth is probably about 200 or 250, although one moth laid 564. The moths mate at night; mating was observed only when they were abundant around lights. The normal life of a moth is from 7 to 10 days.

In the investigation here reported only a single parasite was reared, *Cymodusa mississippiensis* Ashm. Several predacious enemies were observed feeding on both larvae and adults.

The use of ordinary poisoned-bran bait gave no apparent results in the control of the larvae, but by combining it with some attractive substance it is possible that an effective bait may yet be devised.

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TAXATION OF FARM PROPERTY

BY

WHITNEY COOMBS

Senior Agricultural Economist, Division of Agricultural Finance
Bureau of Agricultural Economics

UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D. C.

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TAXATION OF FARM PROPERTY[1]

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Senior Agricultural Economist, Division of Agricultural Finance, Bureau of Agricultural Economics

CONTENTS

KINDS OF TAXES PAID BY AGRICULTURE

An understanding of the kinds of taxes paid by farm owners and operators must form the beginning of any attempt to analyze the present farm tax situation. The general property tax provides the basis for the support of the local units of government and is by far the most important factor in the tax burden of the farm owners. Although many factors of the tax systems vary among the 48 States, in each of them the general property tax stands as the primary source of revenue for the local units. It is a well-known fact that in most sections of the country, the general property tax has become almost wholly a tax on tangible property. For these reasons the major portion of the support of local governmental functions is in the first instance borne by those who possess tangible property. The effects of this on owners of such property will be shown by the figures which appear in a later portion of this bulletin.

Second in importance to the general property tax, so far as the farmer is concerned, are the taxes on automobiles. In general, these are three in number. The first is technically and actually a part of

[1] The material in this bulletin is a summary of the research work in farm taxation which has been carried on during the past eight years. Although the greater portion of this work has been done by the division of agricultural finance of the Bureau of Agricultural Economics, either independently or in cooperation with the State agricultural experiment stations and other State groups, no attempt has been made to restrict the material here used to the results of such investigations. An attempt has been made to acknowledge in the body of the bulletin the source of all material used. The author wishes here to acknowledge his indebtedness to those who by their investigations in various parts of the country have made possiblethis summarization of the work accomplished. Special acknowledgment should be made of the criticisms and suggestions of Eric Englund, who has read the manuscript and discussed many phases of it with the author. Mrs. Thelma M. Penn and Mrs. Martha M. Adams are responsible for much of the statistical material prepared for the bulletin by the Bureau of Agricultural Economics.

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the general property tax—the tax on the automobile as a part of the taxpayer's personal property. It is mentioned here to emphasize the importance of the automobile in the whole tax system.

In a few States, automobiles are not taxed as personal property. Such a tax is considered to be replaced by the second automobile tax, the so-called license tax or tag fee. This is collected in every State. It varies among the States, and within many States, on the basis of the size of the automobile and on various other considerations, such as weight, horsepower, and passenger capacity. All the States at present levy a tax of from 2 to 6 cents a gallon on sales of gasoline for automobile use. The excise tax on the sale of new cars was a fourth tax directly affecting the automobile owners. This was levied by the Federal Government until May 29, 1928. It amounted to 3 per cent of the factory price of new cars and was paid only at the original sale of the car. Although these automobile taxes do not affect all farmers, they are paid by what is probably a great majority of them and so are an important item in the farm-tax budget.

All farmers are subject to the Federal income tax if their incomes are above the exemption limits fixed by law. As the limit for a married man with no dependents is $3,500 of net income, plus $400 for each minor child or other dependent, it will be readily understood that few farmers pay Federal income taxes. This, however, does not mean that no revenue has been secured by the Federal Government from agriculture through the income tax. During the war years of agricultural prosperity, when the exemption limits were lower, many farmers paid income taxes to the Federal Government.

In 12 States an income tax is levied on individual incomes for the support of the State government, with occasional provisions for some distribution to the local units. Although the exemptions in the States are usually lower than those applied by the Federal Government, they are not sufficiently low and the rates are not sufficiently high to secure any important amounts from farmers.

Poll taxes at one time were of considerable importance to agricultural taxpayers. They are now completely absent in many States and form an insignificant portion of the total tax burden in most of the remaining ones.

The State inheritance tax perhaps should be mentioned since farm property, along with other property which changes hand by descent, is subject to this tax in all States but three. As it is by its nature irregular in operation and as the per capita amount collected is insignificant in all States, detailed consideration of it is unnecessary.

Agriculture, like other business, is in some jurisdictions subject to certain fees. The chief of these are the fertilizer and feed-inspection fees which are levied by many States. Such fees are everywhere small in amount and are designed to cover the costs of services that are intended to benefit farmers directly. Fees differ from taxes on this basis; that is, they are designed to cover only the costs of certain services which the governmental units perform.

From this brief summary, it is evident that the forms of taxes which directly affect the farmer are few in number. Two types, those affecting general property and those concerned with the automobile, account for most of the direct tax contributions of farmers. The section that follows will present an estimate of the importance of each of these and of the other minor taxes that are paid by farmers.

Before considering these figures it should be recalled that farmers make many tax contributions indirectly. Whenever they buy goods on which a tariff duty has been levied they are likely to contribute to the costs of the Federal Government. In a similar manner, they make a contribution when they purchase tobacco. To some extent, the merchants in village trading centers are able to pass a portion of the tax on their buildings and their stock of goods on to their customers. No attempt will be made to estimate the amounts of such contributions, but it must be realized that they form a considerable part of agriculture's tax contribution.

AMOUNTS PAID BY AGRICULTURE IN TAXES

An attempt to examine the amounts of taxes paid by agriculture and by agricultural property must be prefaced by the statement that the figures given are in no case more than estimates. They express the judgment of those who have studied the problem, but they do not pretend to be more than approximations of the actual totals. No attempt will be made in the body of this study to explain in detail the methods used in arriving at these estimates. Estimates for the country as a whole for 1927 are contained in Table 1. Certain of the estimates for individual States are included in Table 2.

TABLE 1.—*Taxes paid by farmers in the United States, 1927* [1]

Kind of tax	Amount	Percentage
	Dollars	
General property	755, 000, 000	83. 8
Automobile license	50, 000, 000	5. 5
Gasoline	65, 000, 000	7. 2
Income, Federal and State	15, 000, 000	1. 7
Inheritance, Federal and State	10, 000, 000	1. 1
Poll	6, 000, 000	. 7
Total	901, 000, 000	100. 0

[1] Taxes paid by farmers on other than farm property are not included. Taxes on farm property paid by owners of farm property not themselves farmers are included. No attempt is made in this table to estimate the amount of taxes that are shifted to the farmer by other groups or the amount that the farmer is able to shift to others.

As every farmer realizes, the general property tax which he pays to his county or township treasurer is the most important direct contribution that he makes to defray the costs of government. Almost 84 per cent of agriculture's tax contribution (Table 1) takes this form. It is estimated that the automobile license tax and fees for drivers' permits account for something over 5 per cent of the farm tax total and that the farmer's contribution to the gasoline tax amounts to 7 per cent of his total tax expenditure. Other minor items amount to less than 4 per cent.

Official figures of total tax collections by all governmental units are difficult to obtain, and no attempt is made here to present such figures for the year 1927. Federal taxes for the year were about three and one-third billion dollars, and total State and local taxes were probably around five and one-half billion dollars. On this basis, it is possible to allocate over 10 per cent of all taxes collected as a direct contribution from agriculture. Seventeen per cent of the State and local taxes were derived from this source.

TABLE 2.—*Estimate of certain taxes paid by farmers, by States, 1927*

[In thousands of dollars, i. e., 000 omitted]

State	General property tax on all farm property [1]	License tax on farm-owned automobiles [2]	Tax on farm-used gasoline [3]	State	General property tax on all farm property [1]	License tax on farm-owned automobiles [2]	Tax on farm-used gasoline [3]
Maine	5,767	435	481	North Carolina	16,375	844	2,900
New Hampshire	2,755	345	254	South Carolina	6,588	547	1,575
Vermont	3,245	413	244	Georgia	12,011	1,077	2,544
Massachusetts	6,438	657	--------	Florida	5,012	626	1,427
Rhode Island	483	63	37	Kentucky	12,602	1,135	1,951
Connecticut	3,115	544	275	Tennessee	10,939	791	1,164
New York	20,332	2,858	--------	Alabama	5,619	938	2,186
New Jersey	6,765	648	245	Mississippi	10,728	767	1,810
Pennsylvania	23,446	3,122	2,594	Arkansas	8,495	806	1,215
Ohio	46,233	1,289	3,186	Louisiana	6,677	630	576
Indiana	40,550	1,195	2,523	Oklahoma	21,220	1,496	2,375
Illinois	46,986	1,929	992	Texas	32,835	3,438	4,382
Michigan	28,293	2,338	2,282	Montana	7,899	568	905
Wisconsin	32,912	2,541	1,929	Idaho	7,335	751	912
Minnesota	33,213	2,661	1,656	Wyoming	3,322	147	265
Iowa	50,131	2,800	2,464	Colorado	12,025	288	691
Missouri	20,063	1,981	1,899	New Mexico	3,081	121	410
North Dakota	19,916	686	689	Arizona	2,946	73	222
South Dakota	20,306	1,072	1,293	Utah	4,818	121	336
Nebraska	28,080	1,309	1,576	Nevada	1,200	39	99
Kansas	40,188	2,021	1,608	Washington	12,038	1,037	764
Delaware	548	186	166	Oregon	10,585	1,371	947
Maryland	4,865	538	917	California	39,308	880	2,247
Virginia	9,109	1,518	2,570				
West Virginia	6,639	801	949	United States	754,066	52,441	62,742

[1] Based on returns from farmers and on data published in the reports of the tax commissions of several States. Estimate was made of the tax per acre in farm land and buildings and on all farm property in 1924 in each State. Annual changes as reported on questionnaires received from farmers have been applied to this figure. The result has been multiplied by the total acreage in farms as reported in the 1925 census. This does not take into account changes in farm acreage. Data on which to base an estimate of taxes which would take such changes into account are not available.

[2] This estimate is based on a division of the total amount of receipts from registration as compiled by the Bureau of Public Roads into farm and nonfarm portions. The percentage to be classed as the farm portion is estimated by comparing the estimated number of farm automobiles in each State with total number of automobiles and by taking into account the basis on which the registration fee is levied. Because of a change in the fiscal year involved, North Carolina figures are reported for the second half of 1927 only.

[3] Farm gasoline tax figures are based on the assumption that farm automobiles use a pro rata proportion of the total gasoline taxed by the State. Estimated percentage that farm automobiles are of all automobiles, is applied to the total gasoline tax collected by the State as compiled by the Bureau of Public Roads.

It should once more be recalled that figures of agriculture's tax contribution which have been given represent only the amounts which can be readily computed. No one questions that a contribution in the form of tobacco taxes is made to the Federal Government and to certain State governments by farmers. The agricultural group undoubtedly pays a part of tariff duties levied by the Federal Government. Finally, in the shifting of taxes from one group or individual to another, the farmer usually finds himself as one to whom the tax is shifted. He is rarely able to pass his taxes on to others.

TRENDS IN AGRICULTURAL TAXATION

In any attempt to describe the trend of agricultural taxation, attention must be centered on the few major studies which have been made at various times and in scattered States. No comprehensive data covering the United States as a whole for any long period are available. A study made for the year 1921–22 indicated that taxes per acre of farm land had increased about 125 per cent in the eight years between 1913–14 and 1921–22. Beginning with the year 1924, an annual estimate of taxes on farm real estate based on reports from farmers in all sections of the country has been prepared up to and including 1927. The results of these investigations, together with estimates prepared from such other data as are available for the years between 1914 and 1921 and the year 1923, appear in Table 3.[2] Indexes of farm taxation in three Eastern States also appear in this table.

TABLE 3.—*Index numbers of farm taxes in the United States and in selected States, 1880, 1890, 1900, and 1910–1927*

Year	Tax on farm land and buildings		Tax on all farm property	
	United States, 1914=100	New Jersey,[1] 1915=100	New York,[2] 1910–1919=100	Ohio,[3] 1913=100
1880			69	60
1890			64	69
1900			59	69
1910			82	95
1911			98	87
1912			101	92
1913			105	100
1914	100		113	101
1915	102	100	122	131
1916	104	106	123	129
1917	106	119	143	130
1918	118	122	146	142
1919	136	137	166	170
1920	163	183	198	197
1921	196	224	191	216
1922	232	240	197	210
1923	246	236	219	218
1924	249	254	220	220
1925	250	265	231	232
1926	253	278	234	232
1927	258	292		

[1] The New Jersey figures are preliminary and are based on data collected by the New Jersey Agricultural Experiment Station and the Bureau of Agricultural Economics, U. S. Department of Agriculture, in a cooperative study of farm taxes.
[2] The New York index is taken from (*10*). Italic numbers in parentheses refer to "Literature cited," p. 73.
[3] The Ohio index is from (*11*).

Each year since 1914 has brought an increase in the index for the country as a whole, although since 1923 the change has been relatively slight. The figures for the three individual States do not rise quite so consistently as do those for the country as a whole, but in each case they were at their peak in the last year for which data were secured.

Explanations of the rise in farm taxation over the period from 1914 to the present will be only briefly considered. Part of this increase is accounted for by the change in the purchasing power of money. It took about $1.50 in 1927 to purchase the articles and services that could be secured for $1 in 1914. Governmental units spend the money they collect as do private enterprises, and they are similarly affected by changes in the purchasing power of that money.

Then, too, the services that local governments are called upon to supply have changed during the period. School terms have been lengthened, high schools have been made available to a much larger proportion of the children of the country, and a far larger number

[2] Data for which no footnote credit appears either in the tables or in the text are derived from the investigations of farm taxation carried on by the Division of Agricultural Finance of the Bureau of Agricultural Economics.

of children is attending them. Teachers' qualifications and their salaries have increased. Roads cost far more to maintain now than in 1914 even if they are kept in no better condition. The demands on governmental units for more expensive roads have vastly increased during the period. The two factors, change in the price level and added governmental services, together with the war inflation in farm values, explain most of the increase of farm taxes.

The effect of the inflation in farm values deserves special attention. The peak of farm real-estate prices came in 1920. Increases in assessed values of farm properties necessarily lagged somewhat behind increases in their sales values, but the general tendency was to increase the assessments as quickly as the assessment practices of the State concerned would permit. A lag of the same nature, although longer, had its effect on the downward adjustment of assessments as land prices fell. It is always more difficult for tax officials to lower assessments than to raise them, and at this particular period, increased governmental expenditures made adjustment extremely difficult. These adjustments, however, have been made gradually in most of the States, and a part of the maladjustment of farm taxes has been eliminated. The assessment of farm property is considered in some detail on p. 44. Its effect on farm taxes should not be exaggerated since it directly increased only those taxes which were levied by jurisdictions including farm and other property; that is, by the States and in some cases by the counties.

An index of the changes in the tax per acre on farm land and buildings in various sections of the country for the years since 1924 is contained in Table 4. For the country as a whole there has been a slight increase amounting to about 3½ per cent during the four years 1924 to 1927. This should be contrasted with the material rise in farm taxation that occurred in the years 1919 to 1923, amounting in all to 80 per cent. There was no change of importance for the country as a whole between 1924 and 1925, almost all the increase for the years 1924 to 1927 being about evenly distributed between the two last years of the period.

Although each geographic division of the country experienced some increase in farm taxes from 1924 to 1928, the annual rates of the increase and the aggregate amounts of increase in each division were far from being the same. New England, the South Atlantic, and the Pacific States reported the greatest increases from 1924 to 1928. There has been relatively little change in the east North Central and the west North Central States.

TABLE 4.—*Taxes on farm real estate: Relative change, by geographic divisions, 1924–1928*

[1924=100 per cent]

Geographic division	1924	1925	1926	1927	1928
New England	100.0	100.9	105.4	108.8	111.1
Middle Atlantic	100.0	103.5	103.2	104.5	104.7
East North Central	100.0	99.5	100.3	103.0	102.3
West North Central	100.0	98.4	99.5	100.8	102.9
South Atlantic	100.0	103.5	111.1	111.9	113.7
East South Central	100.0	101.5	103.6	103.4	106.0
West South Central	100.0	100.1	98.6	103.5	107.0
Mountain	100.0	103.2	102.3	104.9	106.0
Pacific	100.0	100.9	102.9	105.6	110.0
United States	100.0	100.3	101.5	103.6	105.1

The assembled data seem to indicate that the period of rapid rise of farm taxes has been passed and that, although a material decline is not to be expected, such increases as may occur in the immediate future will, on the average, be slight. The expansion in governmental services that has characterized the past two decades, particularly in education and highway construction and maintenance, shows little sign of abating. The rate of increase of State and local taxes will be less than it has been, but no general reduction in farm taxes is likely to come from a decrease in total expenditures. It may come either through new methods of financing certain governmental expenditures, such as more State support for the schools, or through the introduction of new sources of local revenues to supplement the general property tax.

TAXES AND AGRICULTURAL INCOME

Two measures of the income from agriculture will be compared with farm taxes. The first of these, the income from rented farm land, is a property income, and little difficulty arises in an attempt to compare it with taxes on property. The second type of income, the return that a farmer receives from the operation of his own farm, combines income from property with income from the farmer's managerial efforts. Thus a mixed income figure is presented for comparison with a tax figure which, although mainly based on farm property, is also based on the farm as a residence and on a small amount of personal household property.

It should be added that the annual value of the farm as a residence does not appear in most of the farm-operation income figures. The qualifications that must accompany a comparison of these figures with taxes will be explained in detail when data relating to them are presented.

TAXES AND INCOME FROM CASH-RENTED FARMS IN 15 STATES

COMPARISON OF CONDITIONS IN 1924 WITH THOSE OF 1919

Data relating to cash rent and taxes of farms in 20 counties in 15 States are presented for the years 1919 and 1924. The figures for the earlier of these two years are taken from the preliminary report [3] of the Bureau of Agricultural Economics. The cash-rent figures for 1924 are those recorded by the Census of Agriculture, 1925. The tax figures for the farms reported upon have been secured from official records in the counties concerned. The methods of securing the data and of calculating the deductions from the gross rent in order to compute a net-rent figure are similar to those used in the 1919 study.[4]

The more recent figures give a good cross section of the income-yielding ability of cash-rented farms in 1924 in several sections of the country. They are of most value, however, in the comparison made in Table 5 with the 1919 results. In every case, except in the two Idaho counties, the two in Colorado, and Merced County, Calif. it will be seen that the tax figure, expressed on a per acre basis, had increased during the period that elapsed between the two studies. Net rent, however, has shown no such tendency. In only six cases was it higher in 1924 than in 1919. The net-rent figures for the various counties in 1919 and 1924 are compared in Figure 1.

[3] BRANNEN, C. O., and SANDERS, J. T. TAXATION OF RENTED FARMS—1919. U. S. Dept. Agr., Bur. Agr. Econ. Prelim. Rpt. 34 p. 1925. [Mimeographed.]

[4] The term "net rent" used without qualification refers in every case to net rent before deducting taxes.

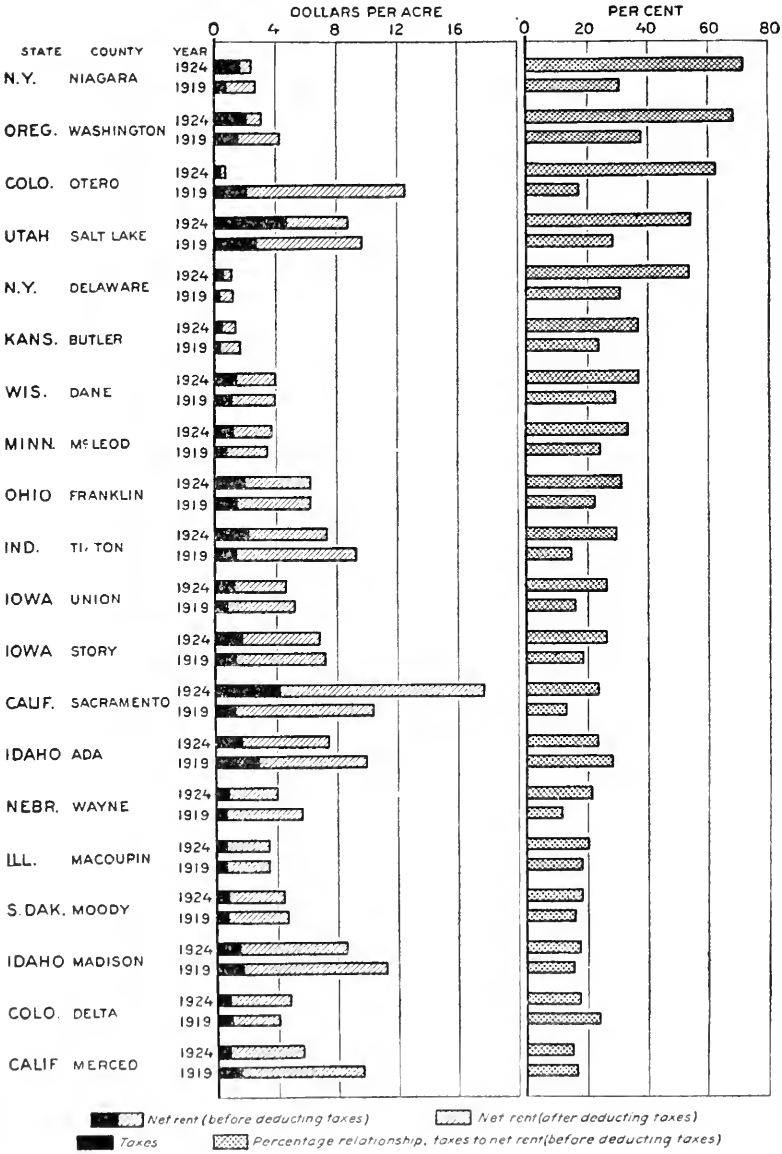

FIGURE 1.—NET RENT AND TAXES OF SELECTED FARMS IN 15 STATES, 1919 AND 1924

Taxes per acre increased from 1919 to 1924 in 15 of the 20 counties, whereas net rent per acre declined in 14 of them. In only 3 of the 20 counties was the percentage of net rent taken by taxes higher in 1919 than in 1924.

TABLE 5.—*Relation of taxes to cash rent of selected farms, 1919 and 1924*

State and County	1919				1924			
	Farms reporting	Net rent per acre	Tax per acre	Tax as a percentage of net rent	Farms reporting	Net rent per acre	Tax per acre	Tax as a percentage of net rent
California:	*Number*	*Dollars*	*Dollars*	*Per cent*	*Number*	*Dollars*	*Dollars*	*Per cent*
Merced	118	9.78	1.63	16.7	104	5.70	0.87	15.3
Sacramento	130	10.49	1.36	13.0	100	17.77	4.23	23.8
Colorado:								
Delta	57	4.04	.96	23.8	40	4.83	.84	17.4
Otero	52	12.63	2.19	17.3	34	.75	.47	62.7
Idaho:								
Ada	66	10.02	2.85	28.4	92	7.51	1.77	23.6
Madison	32	11.31	1.76	15.6	29	8.68	1.53	17.6
Illinois: Macoupin	79	3.52	.64	18.2	74	3.54	.72	20.3
Indiana: Tipton	77	9.38	1.41	15.0	47	7.42	2.22	29.9
Iowa:								
Union	113	5.29	.84	15.9	158	4.70	1.25	26.6
Story	100	7.28	1.37	18.8	113	6.90	1.83	26.5
Kansas: Butler	155	1.73	.41	23.7	133	1.43	.53	37.1
Minnesota: McLeod	87	3.49	.85	24.4	106	3.74	1.26	33.7
Missouri: Bates	------	------	------	------	88	2.36	.48	20.3
Nebraska: Wayne	88	5.74	.67	11.7	96	4.07	.87	21.4
New York:								
Delaware	137	1.23	.38	30.9	112	1.17	.63	53.8
Niagara	86	2.75	.85	30.9	72	2.47	1.78	72.1
Ohio: Franklin	90	6.30	1.41	22.4	155	6.34	1.99	31.4
Oregon: Washington	115	4.34	1.64	37.8	128	3.16	2.17	68.7
South Dakota: Moody	128	4.76	.77	16.2	87	4.49	.81	18.0
Utah: Salt Lake	28	9.81	2.82	28.7	23	8.86	4.82	54.4
Wisconsin: Dane	106	3.98	1.18	29.6	125	4.04	1.49	36.9

Of more significance, perhaps, than the rent or tax figures alone is a comparison between taxes and net rent. Figure 1 indicates the average percentage of net rent paid in taxes for each of the years in each of the counties from which data were obtained. In only 3 of the 20 counties was the percentage lower in 1924 than in 1919. This was to be expected from the analysis of the average net rent and taxes per acre which has already been made. It will be found by detailed examination of Table 5 that in those counties where a material increase ocurred in ratio of taxes to net rent,[5] this increase is due mainly to the rise in taxes rather than to a material decrease in rent.

RENT AND TAXES SINCE 1924

It has not been possible to secure rent figures for years subsequent to 1924 from the farms for which data were presented in that year. Tax figures were secured in every county for 1926 and in most of them for 1927. Table 6 contains the figures of taxes per acre for these years and lists the number of farms for which data were reported in each of the years concerned. This table shows that in 12 of the 21 counties there was an increase from 1924 to 1926 in the tax per acre of the farms for which data were secured. In the remaining 9 counties there was a decrease. Figures for 15 counties are available from 1924 to 1927. In 7 of these there was an increase during the period and in 8 a decrease. In other words, the data available indicate that during the years since 1924 there has been little difference between the number of counties studied in which taxes have increased and the number in which they have decreased.[6]

[5] Where the number of cents taken by taxes from each dollar of net rent has increased by over 25 per cent, the increase has been considered material.

[6] The index of farm taxes for the country as a whole, quoted on page 6, indicates a change of only 3.6 per cent, an increase, for the years in question.

TABLE 6.—*Taxes per acre, of rented farms in 16 States, 1924, 1926, and 1927*

State and county	Farms reporting	Tax per acre		
		1924	1926	1927
	No.	*Dolls.*	*Dolls.*	*Dolls.*
California:				
Merced	81	0.82	0.90	
Sacramento	91	4.03	4.05	
Colorado:				
Delta	35	.93	1.02	0.96
Otero	29	.81	.77	.66
Idaho:				
Ada	84	1.81	1.86	1.83
Madison	27	1.50	1.53	1.60
Illinois: Macoupin	71	.72	.81	.79
Indiana: Tipton	40	2.13	1.91	1.92
Iowa:				
Union	153	1.24	1.04	1.04
Story	106	1.79	1.69	1.63
Kansas: Butler	128	0.53	0.67	0.68
Minnesota: McLeod	102	1.26	1.18	1.11
Missouri: Bates	87	.48	.50	
Nebraska: Wayne	96	.87	.86	.85
New York:				
Delaware	91	.64	.72	
Niagara	64	1.76	1.66	1.67
Ohio: Franklin	154	1.99	1.88	1.80
Oregon: Washington	107	2.12	2.17	2.15
South Dakota: Moody	81	.80	.86	.91
Utah: Salt Lake	23	4.82	4.91	
Wisconsin: Dane	115	1.46	1.37	

The best basis on which an estimate of the rent of farms in these counties for the years since 1924 can rest is a consideration of general conditions in agriculture in these years, as compared with 1924. The gross value of farm production for the crop year 1924–25 was $17,086,000,000, a figure slightly above those of the three subsequent crop years. Gross income from farm production (found by deducting the value of products fed, those used for seed, and waste from the figures just given) was $12,003,000,000 in the crop year 1924–25. It was slightly greater than this in each of subsequent years, although in the first year, 1925–26, it was only 5½ per cent above the 1924–25 level and in the two latter years, it was 1 and 2 per cent, respectively, above that level. Cash income from sales showed almost the same variation except for the fact that in 1926-27 it was below the 1924–25 level.

A comparison of returns from individual farms may be considered before an estimate of changes in rent since 1924 is made. In this estimate only the reports for the northern sections of the country and for the West are considered, as the counties for which rent and tax figures have been gathered are located in these sections. Figure 2 compares the 1924 net returns with those of the subsequent years.[7] The 1925 income figures are consistently greater in each section than those of the previous year. In 1926 net returns fell below those of 1924 in two sections of the country and were above in the other two. The same situation occured in 1927.

Trends in land values are indicated in Table 7. In each area of the country except the West South Central States there has been a decline in land values since 1924. This of itself gives no indication of the trends of income from land, as such income is only one of several factors that determine land values. This may be illustrated by the condition which would arise when income from land is constant, but taxes are rising, both considerably and steadily. The result from these two factors alone would be a decrease in land values. Many other factors might be introduced to explain the lack of a definite correlation over a short period of time between income from land and the value of the land. It is certain, however, that a material and consistent rise in the income from land would, over a period of years, be reflected in value.

[7] The derivation of these figures and their significance from the point of view of this study are considered on page 11. In this particular connection, interest is confined to their year-by-year variation rather than to their absolute amounts.

TABLE 7.—*Farm real estate: Index numbers of estimated value per acre, by geographic divisions, 1924–1928* [1]

[1912, 1913, 1914=100 per cent]

Geographic division	1924	1925	1926	1927	1928
New England	128	127	128	127	127
Middle Atlantic	114	114	113	111	110
East North Central	121	116	111	104	101
West North Central	132	126	121	115	113
South Atlantic	151	148	149	137	134
East South Central	142	141	139	133	130
West South Central	136	144	144	139	137
Mountain	110	105	103	101	101
Pacific	147	146	144	143	142
United States	130	127	124	119	117

U. S. Dept. Agr. Cir. No. 60 (*20, p. 9*).

[1] All farm land with improvements, as of March 1.

In considering the estimate that is to be made of the changes in the rent of land since 1924, one assumption must be kept in mind. This relates to the difference between the territory to which the rent figures

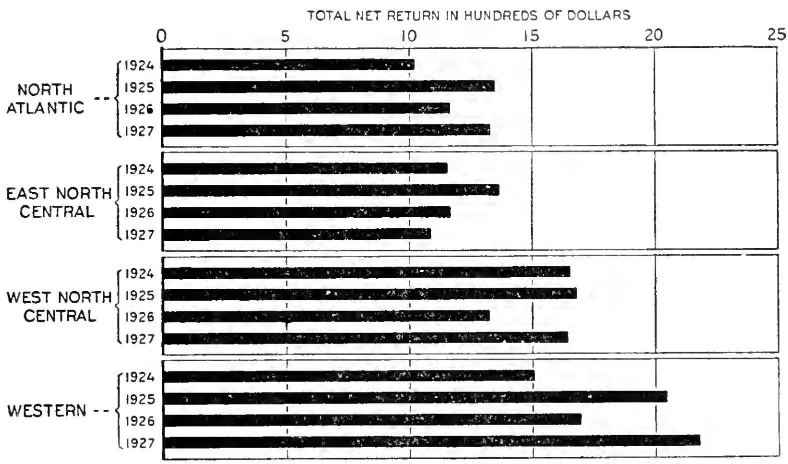

FIGURE 2.—AVERAGE NET RETURNS ON OWNER-OPERATED FARMS IN SELECTED REGIONS, 1924-1927

In each of the regions the 1925 net returns exceeded those of the previous year. In 1926 and 1927 the net returns in only two counties exceeded those of 1924.

that have been used for 1924 relate and the territory covered by the other data. The rent figures are confined to 16 States and at the most to 2 counties within each State. The counties were so chosen as to be as nearly typical of general conditions as possible. But it is realized that they comprise too small a part of the agriculture of the country to be considered as anything more than indications of general conditions. The gross value of production, the farm return, and the land value data relate to the whole country. Thus, any trends which they may indicate will refer only to the particular counties for which data have been presented if these counties are representative of conditions in the country as a whole.

There seems to be little reason for a belief that the net rent of agricultural land increased to any large extent from 1924 to 1927. Land values have declined. Gross income from agriculture was slightly higher in 1925 then in the previous year, but there was little difference between the totals for 1926 and 1927 and that for 1924. The average net return to individual farms was higher in 1925 and 1927 than in 1924, but the increase from 1924 to 1927 was less than 5 per cent. On the whole, it seems a reasonable estimate that net return from land may have increased somewhat, perhaps from 5 to 10 per cent, in 1925; that it dropped back to below its 1924 level in 1926, and may have risen in 1927 to possibly 5 per cent above the point at which it was in 1924.

How would such a change effect cash rent? It seems safe to assume that the fluctuations in cash rent were somewhat less and that they lagged at least a year behind changes in farm returns. From the data considered, it seems a reasonable assumption that cash rent in 1927 was close to the 1924 level.

It has already been shown that taxes changed little from 1924 to 1927. For the country as a whole, there was an increase of appproximately 3 per cent during this period. For the counties studied, the increase seems to be somewhat less. As a result of this examination of changing conditions, it seems a reasonable conclusion that, if it be assumed that the rented farms in 15 States followed the same course as farm land generally, the portion of net rent taken by taxes in 1927 differed little from that taken in 1924.

The number of farms (1,916) included in the 1924 study is obviously too small to justify any general conclusions concerning the relationship between rent and taxes for the country as a whole. All that may be said is that a continued and intensified pressure of taxes on net rent is revealed in many sections of the northern and western portions of the United States. The results obtained from this study of farms in scattered sections of the country add support to the data supplied by the intensive studies which have been made in several of the States.

INTENSIVE STATE STUDIES OF TAXES AND RENT OF FARM LAND

During the last six years, studies concerned with the income and taxation of rented farm land have been completed in 14 States. Although there have been variations in the methods and consequently in the results of these studies, the general purposes and types of information sought have been similar, and, on the whole, it is possible to compare and contrast the results obtained.

These studies have been concerned with the income received by owners of rented farms. For this reason, information has been secured from them rather than from the actual operators of the land. In some of the studies, questionnaires have been mailed to lists of farm owners in the State or section concerned and the results have been tabulated from the questionnaires that were returned. These returns have been subjected to editing, and doubtful ones have been clarified by correspondence or by personal visits.

In other cases the studies have been made by sending an agent to the farm owner from whom information was desired, and schedules containing the relevant facts were filled out by these agents. It is undoubtedly true that this latter method is the more desirable from the point of view of accurate and complete information. Its large cost, as compared with the mail-questionnaire method, has restricted its use. The mail method, in those cases in which the list of owners has been satisfactory, has yielded results which have revealed the general trends and have, on the whole, been sufficient for the present purpose.

Items of information secured on questionnaire or schedule have varied from State to State. Various local interests in income, taxation, or in other subjects, have made this inevitable. The chief items, however, have been everywhere the same. Gross cash or share rent of the particular farm; deductions, such as insurance, repairs, and depreciation; and taxes on the land and buildings of the farm. These items, together with certain others descriptive of the farm, such as total acreage, crop acreage, value, location, etc., have been sufficient for the computation of the necessary figures.

Some emphasis should be placed on the significance of the income from rented farm land. This represents property income and a property income figure is the most significant figure to compare with property taxes. Where rented farm land is uncommon, it is often true that there is not enough competition, either among those who own the land or among those who wish to use the land, to make its rent a satisfactory indication of its income-yielding ability. In the sections of the country in which studies have been carried on, the amount of rented farm land is of significant proportions, and on the average over a period of years, the net rent gives a closer indication of the land's ability to produce income than does any other figure that can be obtained. Share rent often includes a small return to the landlord for his services in supervising the use of his land. In cases where this item is important an allowance has been made for it. No attempt has been made to separate either the rent or the taxes that might be assigned to the residential value of the farm from the total rent or total tax figures.

Studies of the relationship between net rent and taxes have been conducted for one or more years since 1919 in Arkansas, Colorado, Indiana, Iowa, Michigan, Missouri, New Jersey, North Carolina, North Dakota, Ohio, Pennsylvania, South Dakota, Virginia, and Washington.[8]

ARKANSAS

Rented farms in five representative sections of Arkansas were studied (*1*). Data were secured by the local survey method for the 5-year period 1921 to 1925. The number of share and cash rented farms from which data were obtained varied from 122 in 1921 to 178 in 1925. Although the sample is thus rather small, it seems probable that the figures indicate in a general way conditions in the sections of the State which were studied. It was found that over the 5-year period, taxes took, on the average, 18 per cent of the net rent of the farms studied. Table 8 indicates that no great average variation from this figure occured in any year during the period.

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[8] In each of the studies except those in Arkansas, Indiana, and Pennsylvania, the work was carried on by the cooperation of the Bureau of Agricultural Economics and a State agency, usually the agricultural experiment station. In the case of the Indiana study, there was no State cooperation, and in the Arkansas and Pennsylvania studies, the Federal bureau did not cooperate.

TABLE 8.—*General property tax and net rent for selected farms in Arkansas, 1921–1925*

Year	Farms reporting	Acres in these farms	Net rent per acre before deducting taxes	Taxes	
				Per acre	Per centage of net rent before deducting taxes
	Number	*Number*	*Dollars*	*Dollar*	*Per cent*
1921	122	48, 198	2. 84	0. 54	19. 0
1922	129	49, 512	3. 39	. 56	16. 5
1923	145	55, 302	2. 85	. 57	20. 0
1924	162	58, 542	3. 06	. 54	17. 6
1925	178	66, 218	3. 54	. 61	17. 2
Average	147	55, 554	3. 14	. 56	17. 8

Arkansas Agr. Expt. Bul. 223 (*1, p. 8*).

If this report of the study could be extended to include an examination of the reports from each section of the State from which data were secured, it would be found that in the three sections where the most satisfactory number of returns was secured, the annual average percentage of net rent taken by taxes ranged from 30 per cent (in central Arkansas in 1923) to 13 per cent (in northeastern Arkansas in 1922, and in southwestern Arkansas in 1925). Large variations among the figures reported for the individual farms would also be found, taxes on some farms in a particular year taking less than 10 per cent of net rent and on other farms in the same year amounting to more than the total net rent collected.

COLORADO

Data relating to net rent and taxes of farms in Colorado were secured from questionnaires mailed to owners of rented farms (*4*). Reports were requested for the years 1919, 1923, 1925, and 1926. For the first of these years, 282 farms scattered over the State reported average net rent of $2.64 per acre and an average tax payment of 60 cents per acre. Thus taxes took slightly less than 23 per cent of net rent. Reports from 414 farms in 1923 showed net rent averaging $1.80 per acre and taxes 68 cents, with a percentage relationship of taxes to net rent of 38. The last two years for which data were assembled, 1925 and 1926, showed a slightly better situation. With 568 farms reporting in 1925, it was found that taxes took 33.2 per cent of net rent. In 1926, for 304 farms, the corresponding percentage was 32.6. (Table 9.)

An analysis of the reports by agricultural sections of the State indicates that in no section during all the years studied have taxes taken a percentage of net rent materially in excess of that taken in the other sections. Those sections which are subject to excessive variations in annual yields naturally evidenced a variation in net sharerent receipts. Since taxes remained relatively constant, there was a larger variation in the relation between taxes and rent than in those sections in which rent varied only slightly from year to year. Averages for the last three years studied seemed to indicate that there is little difference among the sections in the proportion of net rent used to pay taxes.

TABLE 9.—*General property tax and rent per acre on rented farms in Colorado, 1919, 1923, 1925, and 1926*

Year	Farms reporting	Acres in these farms	Net rent per acre before deducting taxes	Taxes: Per acre	Taxes: Percentage of net rent before deducting taxes
	Number	*Number*	*Dollars*	*Dollar*	*Per cent*
1919	282	88, 832	2. 64	0. 60	22. 7
1923	414	127, 829	1. 80	. 68	37. 8
1925	568	182, 185	1. 84	. 61	33. 2
1926	304	98, 199	1. 78	. 58	32. 6

Colorado Agr. Expt. Sta. Bul. 346 (*4, p. 11*).

When the reports are considered individually, it is found that there is a great difference among farms in the percentage relationship of taxes to net rent. In 1926, one-fifth of the farms reported paid less than 20 per cent of their rent in taxes. About one-fourth of the farms paid from 20 to 40 per cent, and 15 per cent fell into the 40 to 60 per cent group. Thus, three-fifths of all the farms paid less than 60 per cent of their net rent in taxes. Contrasted with these, however, are 89 farms, or 30 per cent of the total number reported, which failed to yield in 1926 enough to enable their owners to pay taxes after the other necessary deductions from gross rent had been made.

INDIANA

The investigation of taxes and rents of farms in Indiana was one of the earliest studies in which this particular type of information was secured.[9] Data for the years 1919 to 1923 were collected by means of a field investigation in three counties of the State—Tipton, Miami, and Monroe. Over the entire period, taxes in these counties amounted to nearly 27 per cent of the net rent received from the farms surveyed.

Detailed figures relating to the survey appear in Table 10. So far as the different years were concerned, there was a large variation in the percentages of rent taken by taxes. In 1919 taxes took only 12 per cent while in 1922 they took over 43 per cent. The different counties studied also showed somewhat different results, taxes forming the largest percentage of net rent in Monroe and the smallest in Tipton.

TABLE 10.—*General property tax and net rent on farms in three counties of Indiana, 1919–1923*

Year	Farms reporting	Acres in these farms	Net rent per acre before deducting taxes	Taxes: Per acre	Taxes: Percentage of net rent before deducting taxes
	Number	*Number*	*Dollars*	*Dollars*	*Per cent*
1919	62	10, 508	7. 49	0. 90	12. 0
1920	79	12, 863	5. 11	1. 11	21. 7
1921	90	14, 970	3. 98	1. 54	38. 7
1922	100	16, 680	3. 71	1. 60	43. 1
1923	105	17, 120	4. 25	1. 41	33. 2
Average	87	14, 428	4. 91	1. 31	26. 7

BRANNEN, C. O., and NEWTON, R. W. Op. cit., p. 4.

[9] BRANNEN, C. O., and NEWTON, R. W. TAXATION OF FARM REAL ESTATE IN INDIANA. U. S. Dept. Agr., Bur. Agr. Econ. Prelim. Rpt. 32 p. 1925. [Mimeographed.]

IOWA

Data relating to rent and taxes in Iowa were secured from a number of sources (*3*). Those for the years prior to 1926 came from farm-survey records which had been compiled by the agricultural economics staff of Iowa State College. For the year 1926, returns from 1,093 rented farms were supplied by the Iowa Farm Bureau Federation. These figures had been secured by representatives of the farm bureau in all sections of the State. Data for 1927 from 862 cash-rented farms were secured by means of a questionnaire circulated by county agents in 74 counties of the State.

Cash rent in 1913 to 1915 averaged $4.26 per acre on the farms surveyed and taxes 61 cents, taxes taking 14 per cent of net rent. The corresponding rent and tax figures in 1926–27 were $4.68 and $1.32, with taxes taking 28 per cent of rent. Share-rent figures are somewhat different, averaging $7.57 in 1913 to 1915 and $5.11 in 1926.[10]

Taxes on these share-rented farms were 58 cents and $1.38, respectively. The percentage of rent taken by taxes on share-rented farms in 1913 to 1915 was 8 per cent, and in 1926, 27 per cent. These figures, together with others for certain of the intervening years, are supplied in Table 11.

TABLE 11.—*General property tax and net rent, cash and share rented farms in Iowa, selected years since 1913*

CASH-RENTED FARMS

Year	Farms reporting	Acres in these farms	Net rent per acre before deducting taxes	Taxes: Per acre	Taxes: Percentage of net rent before deducting taxes
	Number	*Number*	*Dollars*	*Dollars*	*Per cent*
1913	346	71,942	4.18	0.57	13.7
1914	82	13,607	4.58	.66	14.4
1915	104	19,515	4.37	.70	15.9
Total or average	532	104,464	4.26	.61	14.2
1918	85	18,517	5.28	.85	16.0
1921	70	14,222	7.11	1.53	21.6
1922	33	5,496	5.15	1.70	32.9
1923	61	8,941	4.24	1.53	36.1
Total or average	167	28,659	5.84	1.56	26.7
1926	603	101,164	4.90	1.36	27.7
1927	862	166,731	4.54	1.30	28.7
Total or average	1,465	267,895	4.68	1.32	28.3

SHARE-RENTED FARMS

Year	Farms reporting	Acres in these farms	Net rent per acre before deducting taxes	Taxes: Per acre	Taxes: Percentage of net rent before deducting taxes
1913	262	57,430	8.26	0.56	6.6
1914	77	13,186	7.57	.60	7.9
1915	128	26,425	6.07	.64	10.6
Total or average	467	97,011	7.57	.58	7.7
1918	67	12,537	9.90	.74	7.5
1921	42	8,836	5.69	1.52	26.7
1922	203	37,137	7.72	1.56	20.8
1923	73	13,722	4.55	1.58	34.3
Total or average	318	59,995	6.69	1.56	23.3
1926	490	91,905	5.11	1.38	27.0

Iowa State Col. Ext. Bul. 150 (*3, p. 55*).

[10] Reasons for this difference are discussed in THE TAX SYSTEM OF IOWA, (*3, p. 57–58*)

The percentages of net rent absorbed by taxes on individual farms in 1913 and in 1927 are indicated in Figure 3. A comparison is possible, not only of the average percentage, but also of the proportion of all farms that pay the various percentages. The horizontal scale of the figure indicates a percentage of the total number of farms and the vertical scale the percentage of net rent taken by taxes. If there had been no variation from the average percentage; that is, if each farm had paid the same percentage of net rent in taxes, then the solid line

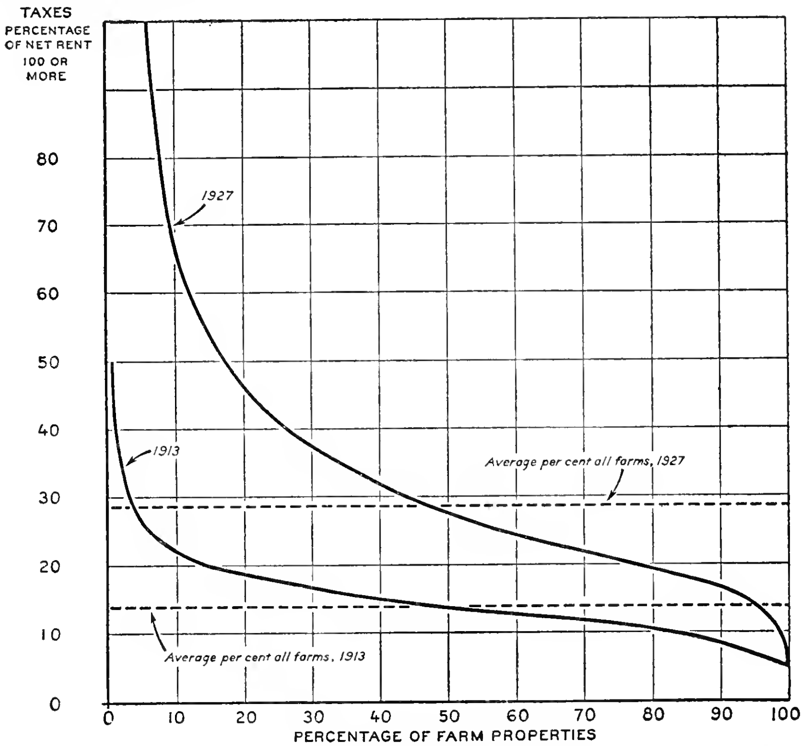

FIGURE 3.—NET CASH RENT AND TAXES ON INDIVIDUAL FARMS IN IOWA, 1913 AND 1927

The variation from the average of the percentage of net rent taken by taxes in individual cases was far greater in 1927 than in 1913.

for each year would have coincided with the dotted line for that year. The variation of each of the solid lines from the dotted line of each year indicates the extent to which the various individual farms failed to conform to the average. Although it is to be expected that the 1927 figures will appear to have a greater variation from the average than those of 1913, because of the larger amounts involved, no such variation as that which appears in the figure would be caused by this factor alone.[11]

[11] The coefficients of variation for the years 1913 and 1927 are 42 and 75 per cent, respectively.

MICHIGAN

An investigation of taxes and income from rented farms to include the years 1919 to 1926 has been made in Michigan (*12*). Both from the point of view of the representativeness of the data for any particular year and of the period covered, the results of the study rank with the best that have been secured. In all, data from over 1,500 farms of the lower peninsula were considered in the preparation of the final figures.

Average net rent for the 8-year period 1919 to 1926 amounted to $2.75 per acre, with taxes averaging $1.44 still to be deducted before the owner could figure his net return. Thus taxes averaged 52 per cent of net rent over the period. Table 12 indicates this relationship for each of the years covered.

TABLE 12.—*General property tax and rent per acre, Michigan, 1919–1926*

Year	Farms reporting	Acres in these farms	Net rent per acre before deducting taxes	Taxes	
				Per acre	Percentage of net rent before deducting taxes
	Number	*Number*	*Dollars*	*Dollars*	*Per cent*
1919	521	60, 654	4. 31	1. 29	29. 9
1920	392	43, 956	2. 99	1. 49	49. 8
1921	415	46, 546	2. 17	1. 53	70. 5
1922	656	76, 483	2. 66	1. 49	56. 0
1923	578	63, 954	2. 25	1. 51	67. 1
1924	677	73, 570	2. 44	1. 41	57. 8
1925	1, 018	115, 177	2. 69	1. 46	54. 3
1926	[1] 614	69, 396	2. 50	1. 37	54. 8
Average	609	68, 717	2. 75	1. 44	52. 4

Michigan Agr. Expt. Sta. Tech. Bul. 91 (*12, p. 5*).

[1] These farms reported for each of the years, 1925 and 1926.

An analysis of the Michigan returns by sections of the State shows a considerable variation in the proportion of net rent taken by taxes. For the 7-year period, 1919 to 1925, the highest average percentage of rent consumed by taxes was reported from 7 northwestern counties of the lower peninsula. This percentage amounted to 92. During the 4-year period, 1920 to 1923, average taxes in these counties were actually greater than rents. In 1926 the rent and tax condition of the farms in these counties was materially better. Taxes averaged 58 per cent of net rents. At the other extreme was a group of eastern and central counties where taxes for the 7-year period, 1919 to 1925, were, on the average, 46 per cent of the net rents. Here the rent and tax situation became much worse in 1926, taxes taking 61 per cent of net rent. Figure 4 illustrates the annual variations from 1919 to 1926 in different sections of the State.

Although differences among the sections were important, those between individual farms were far more striking than the average quoted figures would indicate. In 13 counties of central and lower Michigan reports were received from 451 farms in 1925. Of these farms, all of which reported some gross income, 56 had a deficit before paying taxes; that is, expenses other than taxes were greater than gross rent. Of 75 others, taxes took more than the total net rent.

In 1919, reports on 233 farms in these same counties had been received. The reports indicated a deficit for 18 farms in this year before taxes were paid and in 23 others a deficit after taxes were paid.

In 1919 and 1925, respectively, 18 and 29 per cent of the rented farms reported, yielded no net income to their owners after taxes had

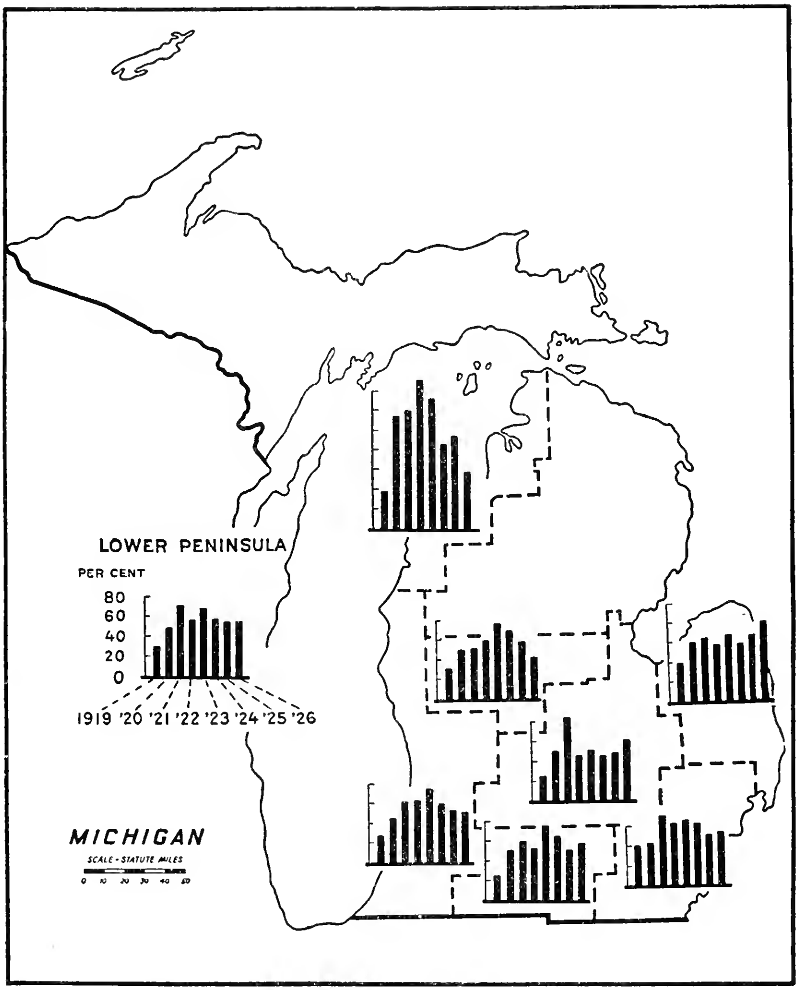

FIGURE 4.—PERCENTAGE RELATIONSHIP OF TAXES IN FARMS IN SEVEN DISTRICTS OF THE LOWER PENINSULA OF MICHIGAN, 1919-1926

The percentage of net rent taken by taxes from 1919 to 1926 averaged highest in the northwestern counties of the lower peninsula. For the lower peninsula as a whole the percentage was at its peak in 1921. It declined the following year, rose again in 1923, and then dropped in 1924 and 1925. It was practically the same in 1926 as it had been the previous year.

been paid. It will be observed that there was a pronounced increase during this period in the proportion of farms for which a failure to yield any return to their owners was reported.

Among the farms that yielded a return in the years in question, there was a great variation in each of the years in the proportion of the net rent which was taken by taxes. Although the average percentage taken was lower in 1919 than in 1925, there was only a little difference in the two years in the way the individual farms varied above and below these averages.[12] In 1919 taxes took 25 per cent or less of the net income of half the income-yielding farms, whereas in 1925 only one-fourth of the income-yielding farms paid 25 per cent or less. Similarly, in 1919 three-fourths of the farms paid 50 per cent or less, and in 1925 two-fifths paid 50 per cent or less in taxes.

Some emphasis is placed on this analysis of the data in this State and elsewhere as the average figures that are most often quoted fail to reveal all of the real situation, as relatively few actual farms may be found to be paying in taxes a percentage of income which is reasonably close to the average percentage.

MISSOURI

Field agents secured data from rented farms for the years 1919 to 1923 in four counties of Missouri—Gentry, Boone, Audrian, and New Madrid (*2*). In 1923 it was found that taxes absorbed 20 per cent of the net rent of the 256 farms studied in these counties. In 1919 taxes had taken only 10 per cent of the net rent. Over the 5-year period, 1919 to 1923, the percentage taken by taxes was slightly above 16. The increase was due mainly to the rising level of taxation rather than to a drastic decline in net rent. The major portion of the tax increase in these counties occurred from 1920 to 1921. Table 13 contains the average annual tax and rent figures which were secured in this portion of the study.

TABLE 13.—*General property tax and net rent per acre on selected farms in Missouri, 1919–1923*

Year	Farms reporting	Acres in these farms	Net rent per acre before deducting taxes	Taxes	
				Per acre	Percentage of net rent before deducting taxes
	Number	*Number*	*Dollars*	*Dollar*	*Per cent*
1919	73	13, 640	4. 71	0. 47	10. 0
1920	82	15, 338	4. 32	. 55	12. 7
1921	103	18, 716	3. 69	. 81	22. 0
1922	145	26, 789	4. 02	. 73	18. 2
1923	256	49, 265	3. 73	. 75	20. 1
Average	132	24, 750	4. 09	. 66	16. 1

Missouri Agr. Expt. Sta. Research Bul. 93 (*2, p. 6*).

[12] The coefficients of variation for the nondeficit farms for 1919 and 1925 are 67 and 52 per cent, respectively. This difference would be largely eliminated if the larger number of deficit farms in 1925 were taken into account.

TABLE 14.—*General property tax and net rent per acre, northwestern counties of Missouri, 1913–1922*

Year	Farms reporting	Acres in these farms	Net rent per acre before deducting taxes	Taxes	
				Per acre	Percentage of net rent before deducting taxes
	Number	*Number*	*Dollars*	*Dollar*	*Per cent*
1913	21	4, 328	3. 09	0. 35	11. 3
1914	25	4, 955	2. 95	. 33	11. 1
1915	29	5, 987	3. 12	. 32	10. 2
1916	37	6, 933	3. 31	. 32	9. 7
1917	49	8, 867	3. 54	. 35	9. 9
1918	58	10, 299	3. 83	. 36	9. 3
1919	86	14, 279	4. 66	. 48	10. 4
1920	103	17, 724	4. 68	. 53	11. 4
1921	141	23, 231	4. 42	. 71	16. 0
1922	206	33, 403	4. 26	. 73	17. 1

Missouri Agr. Expt. Sta. Research Bul. 93 (*2, p. 7*). Percentages have been computed from totals and not from the derived per-acre figures.

The data contained in Table 14 are based on a survey of cash-rented farms in 23 counties in the northwestern part of the State and indicate that the recent increase in taxes did not begin until after 1918 and that, up to that year, taxes had taken a small and declining portion of net rent. A drastic increase of taxes from 1918 to 1919 was accompanied by an increase in net rent with the result that taxes took only a slightly greater percentage of net rent in 1919 than in the preceding year. Another sharp increase in taxes came from 1920 to 1921. This, however, was accompanied by a decline in net rent. The percentage of rent paid in taxes increased from 11.4 in 1920 to 16 in 1921.

NEW JERSEY

Data were secured by questionnaire from 98 rented farms in New Jersey for the year 1927.[13] This number is small, but it should be recalled that there are only 4,723 rented farms in the State, so that data for 1927 were recorded from more than 2 per cent of the rented farms. The farms reporting were well distributed throughout the State and probably indicate general conditions with fair accuracy. Net rent per acre in 1927 amounted to $4.41. Taxes were $2.12 per acre, thus amounting to 48 per cent of net rent. These figures are compared with those for 1925 and 1926 in Table 15. Taxes and rent increased in the years 1926 and 1927. The increase in net rent was greater proportionately than that of taxes, with the result that the ratio of taxes to net rent decreased in each of these years.

[13] The results of this study will be published in the near future by the New Jersey Agricultural Experiment Station in cooperation with the Bureau of Agricultural Economics.

TABLE 15.—*General property tax and net rent for selected farms in New Jersey, 1925–1927*

Year	Farms reporting	Acres in these farms	Net rent per acre before deducting taxes	Taxes	
				Per acre	Percentage of net rent before deducting taxes
	Number	*Number*	*Dollars*	*Dollars*	*Per cent*
1925	83	10,682	3.74	2.03	54.3
1926	91	11,650	4.09	2.07	50.6
1927	98	13,185	4.41	2.12	48.1
Average	91	11,839	4.08	2.07	50.7

Reports from 79 farms for each of the three years of the period 1925 to 1927 are available. Over the whole period net rent per acre on these farms averaged $4.48. Taxes averaged $2.13 per acre and the portion of net rent taken by taxes 47.5 per cent. The annual figures for these 79 farms indicate a progressively improving relationship in the tax and rent situation. The percentage relationship of taxes to net rent in 1925 was 51. The following year it had fallen to 48, and in 1927 it was 44. This occurred in spite of an increase in taxes from $2.04 per acre in 1925 to $2.24 in 1927. It is explained by the much greater increase in net rent, which rose from $3.98 per acre in 1925 to $5.09 in 1927.

NORTH CAROLINA

A study of 416 rented farms widely distributed over the State furnished rent and tax figures for North Carolina in 1927 (*16, p. 46–203*). Reports were secured for the years 1925 to 1927. In the latter year, net rent averaged $695 per farm and $3.04 per acre. Taxes the same year averaged $201 per farm and 88 cents per acre. Thus taxes amounted to 29 per cent of net rent.

Table 16 gives the figures for 1925–1927. Both taxes and net rents were lower in the earlier years, whereas the percentage of net rent taken by taxes was slightly higher, 35 in 1926 and 33 in 1925. Taxes took, in each of the years, a greater percentage of the net rent of cash-rented farms than of those rented on shares. This may partly account for the fact that the average percentage taken by taxes was higher in the two earlier years than in 1927, as cash-rented farms composed the majority of those reported in 1925 and 1926, but were in the minority in 1927.

TABLE 16.—*General property tax and net rent on selected farms in North Carolina, 1925–1927*

Year	Farms reporting	Acres in these farms	Net rent per acre before deducting taxes	Taxes	
				Per acre	Percentage of net rent before deducting taxes
	Number	*Number*	*Dollars*	*Dollar*	*Per cent*
1925	160	33,041	2.19	0.73	33.3
1926	182	35,501	2.21	.77	34.8
1927	416	95,205	3.04	.88	28.9
Average	253	54,583	2.48	.79	31.9

Report of the tax commission of North Carolina (*16, p. 161*). (Table corrected and 3-year average computed.)

Farms reporting from the coastal plain in 1927 yielded an average of $926 to their owners after paying all expenses except taxes. This latter item amounted to $252 per farm, or 27 per cent of net rent. The majority (66 per cent) of the farms reporting were in that section of the State. The mountain section was represented by only 18 farms These reported taxes amounting to over two and one-half times the net rent. On 33 farms in the tidewater section, taxes amounted to one-half of the net rent, and on 89 farms in the Piedmont, taxes took one-third of the owners' net rent.

NORTH DAKOTA

Rent and taxes for the years 1921 to 1924 were studied on farms in three counties of North Dakota—Traill in the eastern part of the State, Wells in the central part, and Hettinger in the western part; and data were secured in two of the counties, Traill and Wells, for two earlier years, 1919 and 1920 (*13*). Table 17 shows that taxes averaged about 40 per cent of the net rent for the years which the investigation covered. In the four years 1920 to 1923 they took practically 50 per cent of the net rent.

TABLE 17.—*General property tax and net rent per acre on selected farms in North Dakota, 1919–1924*

Year	Farms reporting	Acres in these farms	Net rent per acre before deducting taxes	Taxes	
				Per acre	Percentage of net rent before deducting taxes
	Number	*Number*	*Dollars*	*Dollar*	*Per cent*
1919	45	14, 567	2. 36	0. 35	14. 8
1920	62	22, 317	1. 30	. 60	46. 2
1921	91	29, 877	1. 05	. 63	60. 0
1922	117	36, 211	1. 32	. 64	48. 5
1923	155	46, 769	1. 03	. 61	59. 2
1924	158	46, 694	3. 18	. 50	15. 7

North Dakota Agr. Expt. Sta. Bul. 203, (*13, p. 15*). Figures from two counties in 1919 and 1920 and from three in the remaining years.

One finding of this study deserves particular notice. The tax condition of the farms was, so far as net rent is concerned, as favorable in 1924 as in 1919. This is accounted for by the high net rents received in 1924. In Wells County, the 1924 rent figure was almost twice that of 1919, and in Traill County it was nearly 65 per cent greater than in the earlier year. Taxes in Wells County increased 86 per cent during the period and those in Traill 56 per cent. The greater portion of the tax increase in these two counties came from 1919 to 1920. Since 1922 taxes in each of them have declined.

When changes in the average tax figure are studied, it is found that they do not correspond in their rise or fall to rent figures. Other instances of this maladjustment of incomes and taxes have been noted in the case of individual farms as well as in average results. It is experienced in any section in which there are large annual variations in the income-producing capacity of farm lands. As is illustrated by the North Dakota figures, taxes decline only slightly, if at all, from one year to the next, whereas incomes are frequently subject to drastic decreases.

OHIO

In Table 18 are tabulated the results of a study of cash rents and taxes in Ohio from the years 1913 to 1922. The particular value of these data arises from the fact that they cover a 10-year period during which farm taxes increased at a greater rate than they have at any other during the past 50 years. Cash rent on these Ohio farms increased with some irregularity from 1913 to 1920 and declined in the years 1921 and 1922. Taxes increased in every year of the period except 1916. Cash rents in 1922 were 33 per cent above those reported in 1913, whereas taxes were 128 per cent above the earlier year. In 1913 taxes took 24 per cent of net rent. This percentage declined slightly in 1914, increased somewhat the following year, and remained practically constant in 1916. Thereafter there was up to 1922, and with a minor exception in 1919, an almost steady increase in the percentage, which reached 41 in the last year of the period.

TABLE 18.—*General property tax and net rent per acre on selected cash rented farms in Ohio, 1913–1922*

Year	Farms reporting	Acres in these farms	Net rent per acre before deducting taxes	Taxes	
				Per acre	Percentage of net rent before deducting taxes
	Number	*Number*	*Dollars*	*Dollars*	*Per cent*
1913	31	4,578	3.00	0.72	23.8
1914	37	5,392	3.41	.73	21.4
1915	37	5,207	3.35	.90	26.9
1916	54	6,517	3.38	.89	26.3
1917	69	7,984	3.70	1.07	28.9
1918	91	10,941	3.79	1.22	32.2
1919	115	13,271	4.27	1.33	31.1
1920	147	16,232	4.37	1.48	34.0
1921	176	19,928	4.25	1.61	37.8
1922	277	31,850	3.99	1.64	41.0

BRANNEN, C. O., and NEWTON, R. W. Op. cit., p. 9.
Percentages have been computed from totals and not from the derived per-acre figures.

PENNSYLVANIA

Reports of taxes and rents on Pennsylvania farms that are summarized in Table 19 are rather meager in number and cover only one year (*19*). They do present a fairly large sample from Lebanon County and a few farms from Lancaster County, representing the better agriculture of the State. The sample from Warren and Westmoreland Counties, representing, from the agricultural point of view, some of the less productive counties of the State, is not sufficient to justify any conclusions.

The great differences between the two groups of counties in the percentage of net rent taken by taxes may indicate that conditions in Pennsylvania, as elsewhere, make necessary heavy demands on the poorer sections of the State for certain governmental services which are easily met by those portions of the State where incomes are higher. In other words, the cost of governmental services tends to remain fairly constant even if the wealth of various sections of the State or the incomes of those sections vary.

TABLE 19.—*General property tax and net rent per acre on selected farms in Pennsylvania, 1924–25*

County	Farms reporting	Acres in these farms	Net rent per acre before deducting taxes	Taxes	
				Per acre	Percentage of net rent before deducting taxes
	Number	*Number*	*Dollars*	*Dollars*	*Per cent*
Lancaster	7	490	16.41	1.96	11.9
Lebanon	55	5,655	7.40	1.82	24.6
Warren	5	1,041	.74	.54	73.0
Westmoreland	8	923	4.16	2.63	63.2

Computed from data supplied by F. P. Weaver (*19*).
The average for these counties should not be assumed as representing the State as a whole because the arms in these counties may not be typical of all farms.

SOUTH DAKOTA

Rented farms in Brookings, Beadle, Day, Hamlin, and Pennington Counties of South Dakota were studied in order to secure income and tax figures for the years 1919 to 1926 (*5*). Data were secured over this 8-year period for, on an average, 151 farms. The counties in which these farms are located are well distributed over the State, and although the sample is small, the results of the study probably represent to a fair degree the general situation.

Rent and tax levels differ considerably among the counties. The average net rent per acre for the 8-year period was $3.34 in Brookings, $2.79 in Beadle, $1.82 in Day, $3.23 in Hamlin, and $0.96 in Pennington. Taxes per acre averaged 89, 82, 73, 83, and 21 cents respectively, in these counties. As this would indicate, there was great variation among the counties in the number of cents which were paid out in taxes from each dollar of net rent. For the whole period from 1919 to 1926, inclusive, the owner of a rented farm in Pennington County paid out in taxes on an average 22 cents of each dollar of net rent, whereas in Day County 40 cents, or nearly twice the amount in Pennington County, was paid out. The other counties fall between, the number of cents paid in taxes per dollar of net rent averaging 26 in Hamlin, 27 in Brookings, and 29 in Beadle.

The average figures for the whole period tell only part of the story. In Day County in 1921 taxes were $1.20 for every dollar of net rent. In Pennington, the same year, they were $1.13. This was due in each of the counties to drought and hail, which came along with low prices for agricultural products. At the other extreme, in Pennington County in 1924, farmers paid out in taxes less than 7½ cents of every dollar of net rent. In other words, although taxes in 1921 seemed confiscatory, if conditions were judged from that year only, three years later in the same county they were so small as to constitute a minor deduction from income.

Table 20 summarizes the 8-year figures of the farms reported from South Dakota. The qualifications placed upon the use of average figures should be observed here as elsewhere. The averages do, however, illustrate trends and so are worth consideration. Net rent per acre was highest and taxes were lowest in 1919, the percentage relationship of taxes to net rent being 16. Two years later rent had fallen to $1.30 per acre and taxes had risen to 71 cents, with the result that taxes took 55 per cent of net rent. From that year through 1924, there was an improvement each year in the rent figure with only a slight change in the taxes. In 1924 taxes took 21 per cent of net rent. A slight decline in rent occured in 1925 and a material decline in 1926. There was little change in taxes during these years, taxes amounting to 23 per cent of net rent in 1925 and to 30 per cent in 1926.

TABLE 20.—*General property tax and net rent per acre on selected farms in South Dakota, 1919–1926*

Year	Farms reporting	Acres in these farms	Net rent per acre before deducting taxes	Taxes	
				Per acre	Percentage of net rent before deducting taxes
	Number	*Number*	*Dollars*	*Dollar*	*Per cent*
1919	178	60,066	3.79	0.61	16.1
1920	127	47,817	1.76	.74	42.0
1921	132	49,203	1.30	.71	54.6
1922	132	48,974	1.68	.71	42.3
1923	133	49,850	2.01	.66	32.8
1924	192	64,249	3.33	.69	20.7
1925	164	44,976	3.16	.72	22.8
1926	142	38,054	2.38	.71	29.8
Average	150	50,399	2.43	.69	32.6

South Dakota Agr. Expt. Sta. Bul. 232 (*5*, *p. 30*).

VIRGINIA

Reports of taxes and rents for 1926 were secured from 1,094 farms located in 33 counties of Virginia.[14] This sample is large enough to represent the various portions of the State in which rented land is of importance. The average net rent of the farms from which reports were secured was $2.12 per acre, and out of this taxes amounting to 42 cents had to be paid. Thus, taxes took 20 per cent of the net rent of these farms.

The State was divided into several districts for the purpose of the survey. The farm data secured in each district appear in Table 21. Farm taxes in relation to income were highest in the eastern district, where taxes took 33 per cent of the net income of the 91 farms for which data were secured. In the locality designated as the Blue Ridge, owners of the 92 farms reporting paid 29 per cent of their net rent in taxes. At the other extreme, so far as rent and taxes are concerned, were 113 farms of the valley north district, where taxes took less than 16 per cent of net rent. The sections designated as northern, South I, and South II had results which were not greatly different from those of the valley north.

[14] A detailed report of this investigation will be published by the Virginia Agricultural Experiment Station in cooperation with the Bureau of Agricultural Economics.

TABLE 21.—*General property tax and net rent per acre on selected farms in 33 counties of Virginia, 1926.*

District	Farms reporting	Acres in these farms	Net rent per acre before deducting taxes	Taxes	
				Per acre	Percentage of net rent before deducting taxes
	Number	*Number*	*Dollars*	*Dollar*	*Per cent*
Southwest	111	34, 610	2. 00	0. 46	23. 0
Valley central	148	30, 870	3. 03	. 55	18. 1
Valley north	113	19, 666	4. 05	. 64	15. 9
Northern	96	27, 745	2. 95	. 48	16. 2
Eastern	91	20, 761	1. 10	. 36	32. 8
Eastern Shore	100	14, 020	3. 37	. 77	22. 8
Southeast	113	21, 388	1. 34	. 34	25. 2
South I	111	24, 433	1. 37	. 27	19. 6
South II	119	29, 208	1. 41	. 23	16. 6
Blue Ridge	92	22, 791	. 99	. 29	29. 4
Total or average	1, 094	245, 492	2. 12	. 42	20. 0

Counties represented in the reports of each of the districts follow: Southwest—Washington, Smyth, Pulaski, Russell, Tazewell, Montgomery; valley central—Alleghany, Bath, Botetourt, Rockbridge, Augusta; valley north—Rockingham, Frederick; northern—Loudoun, Fauquier; eastern—Westmoreland, Essex, Hanover, Henrico; Eastern Shore—Accomac; southeast—Nansemond, Prince George, Sussex; South I—Brunswick, Lunenburg, Prince Edward, Cumberland; South II—Halifax, Pittsylvania; Blue Ridge—Carroll, Bedford, Amherst, Albermarle. Percentages have been computed from totals and not from the derived per-acre figures.

In Virginia, as elsewhere, the difference between the reports of individual farms and the average was striking. Figure 5 illustrates these variations for the State as a whole and for certain sections. About 12 per cent of the farms from which reports were received in 1926 yielded no net rent to their owners after taxes and other expenses had been paid. Taxes took 50 per cent or more of the net rent on 22 per cent of the farms. On the other hand, 3 per cent of the farms paid 5 per cent or less of their net rent in taxes and 12 per cent of the farms paid between 5 and 10 per cent.

WASHINGTON

Reports from 406 rented farms in Washington were secured for 1926. The owners of these farms had received net rent averaging $2.71 per acre from which it was necessary for them to pay 79 cents per acre in taxes. Table 22 indicates that the situation in 1926 was not greatly different from that in the two previous years. Net rent was 9 per cent higher in 1925 and 4 per cent lower in 1924 than in 1926. Taxes were the same in 1925 as in 1926 and were 4 per cent higher in 1924. The percentage of net rent taken by taxes for the 3-year period averaged 29, which was its 1926 level. A slightly larger proportion of net rent was taken by taxes in 1924 and a somewhat smaller proportion in 1925.

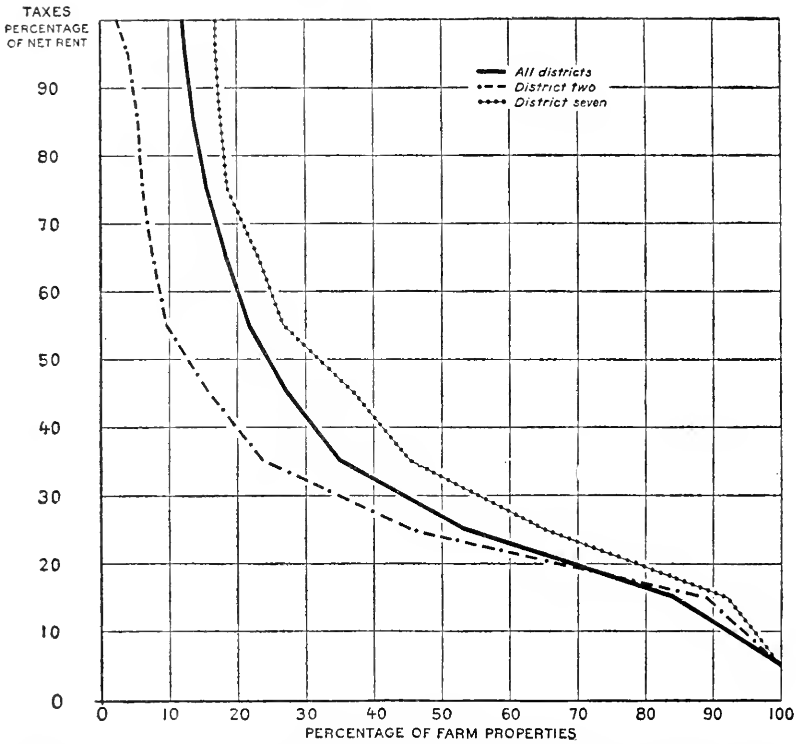

FIGURE 5.—PERCENTAGE DISTRIBUTION BASED ON RELATION OF TAXES TO NET RENT ON FARMS IN VIRGINIA—IN THE STATE AS A WHOLE AND IN SELECTED DISTRICTS—IN 1926

One hundred forty-eight reports in district 2 which were collected from Alleghany, Bath, Botetourt, Rockbridge, and Augusta counties show a greater concentration of farms paying from 10 to 20 per cent of their net rent in taxes than do the 1,093 reports from the whole State. Only a small number of farms in district 2 (the central valley) fail to yield enough net rent to pay taxes and all other expenses. District 7 (southeastern Virginia), comprising 113 reports from Nansemond, Prince George, and Sussex Counties, has a large per cent of its farms in the higher percentage groups than has district 2 or the State as a whole.

TABLE 22.—*General property tax and net rent per acre on selected farms in Washington, 1924–1926*

Year	Farms reporting	Acres in these farms	Net rent per acre before deducting taxes	Taxes	
				Per acre	Percentage of net rent before deducting taxes
	Number	*Number*	*Dollars*	*Dollar*	*Per cent*
1924	359	123, 910	2. 59	0. 83	32. 0
1925	382	134, 744	2. 96	. 79	26. 7
1926	406	143, 767	2. 71	. 79	29. 2
Average	382	134, 140	2. 75	. 80	29. 1

Owners of the farms reported on for the 3-year period 1924 to 1926 from the Palouse country of southeastern Washington paid on an average 23 per cent of their net rent in taxes. These farms yielded to their owners annually from 1924 to 1926 $3.19 per acre in net rent, from which taxes of 73 cents had to be paid. Owners of farms in the irrigated sections of central Washington reported that they paid 27 per cent of their net rent in taxes. Their annual net rent averaged $9.61 per acre, and taxes $2.61. Tax figures given here and elsewhere do not include water charges or other special assessments. Farmers of the Columbia Plateau reported that taxes took 29 per cent of their net rent. Taxes in this section of the State averaged 42 cents per acre and net rent $1.44. The relationship between taxes and net rent in western Washington was less favorable than in the three sections just described. Although net rent at $4.79 per acre was well above the average for the State, taxes amounted to $2.09 per acre. Thus taxes in western Washington took 44 per cent of the net rent.

TAXATION OF RENTED FARMS SUMMARIZED

If the discussion of taxes and rent of farms in 14 States located in all sections of the country could be extended to the other 34 States, new evidence of the weight of taxation on farm real estate would be obtained, but it is doubtful whether any condition of this single aspect of the problem would be disclosed that has not been revealed by the studies already completed. It will be profitable, however, to attempt to bring together these results and to try to discover what they contain of importance to one who wishes to understand the farm-tax situation.

A diagrammatic summary of the studies is presented in Figure 6. The data that appear in the figure are largely self-explanatory, but their interpretation required considerable study. The data refer to different years, because the various investigations have not been concerned with any one year or series of years. Even if a single year common to all the investigations could be chosen, there would be grave objections to its use. Any one year might fail to reveal the situation within a State since there could be no guaranty that the figures for that year were not abnormal.

In order to secure as accurate a description as possible of the general situation in each of the States, data for two or more years have been combined wherever possible. In only one case have data for a year prior to 1922 been used. By using returns for the more recent years a picture of more stabilized agricultural conditions can be presented than would be indicated by using data from the years 1919 to 1921 along with those for the more recent years. In the single case of Ohio the years 1921 and 1922 are the most recent years for which data are available. It is considered that the use of the figures for these two years gives a more balanced picture than would be obtained by using 1922 alone.

Total net rent before taxes were deducted is highest for the few farms reported from Pennsylvania. Inadequacies of the data from that State have been mentioned. Figures of net rent that adequately represent the State would undoubtedly be lower, and the ratio between taxes and net rent would probably be higher. In Iowa, New Jersey, and Ohio per-acre net rent figures for over $4 were reported, and those in Indiana and Missouri lacked only a few cents of this amount. Arkansas figures indicate an average rent per acre amounting to over $3. Michigan, North Carolina, South Dakota, Virginia, and Washington fall into the class reporting net rent of between $2 and $3 per acre. Colorado and North Dakota each average slightly under $2 per acre.

The farms of four States—New Jersey, Pennsylvania, Ohio, and Indiana—reported an average tax per acre of $1.50 or over. Iowa and Michigan had per-acre tax figures of between $1 and $1.50. All the remaining States of the group studied, except Virginia, fall into the group reporting taxes of from 50 cents to $1 per acre. Virginia's tax per acre was 42 cents.

Pennsylvania figures show the largest average net rent per acre after taxes had been deducted, but these figures are almost wholly

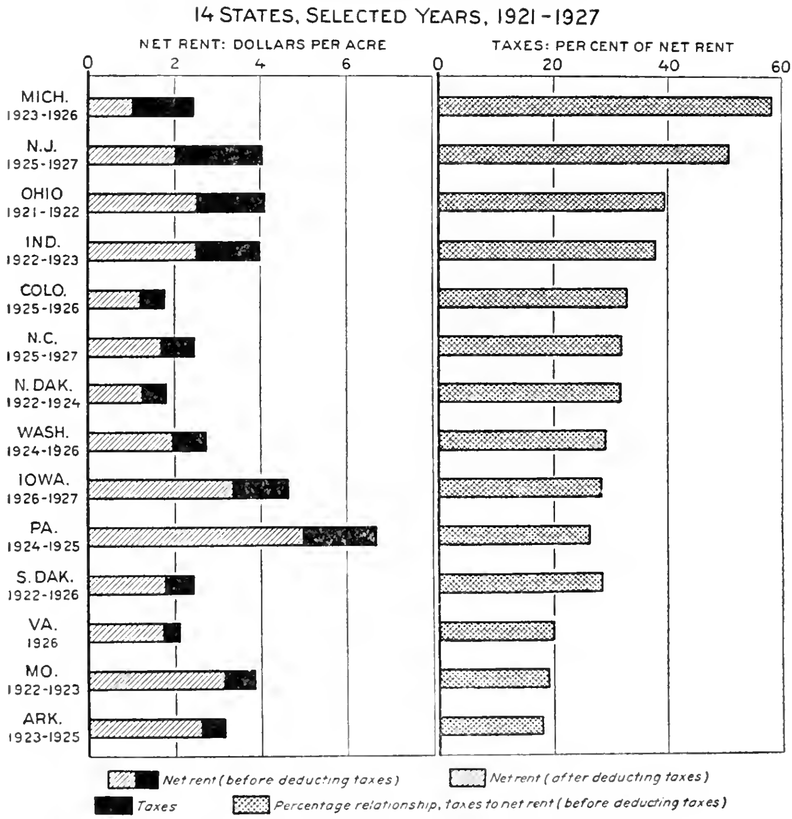

FIGURE 6.—GENERAL PROPERTY TAX AND NET RENT, SELECTED FARMS IN 14 STATES, SELECTED YEARS, 1921-1927

In Michigan and New Jersey taxes during the periods indicated amounted to over 50 per cent of the net rent before taxes were deducted. At the other extremes, in Virginia, Missouri, and Arkansas taxes amounted to 20 per cent or less of net rent.

derived from the better farms of the State. Iowa and Missouri report average net rent after taxes had been deducted amounting to between $3 and $4 per acre. Arkansas, Indiana, Ohio, and New Jersey are in the group reporting from $2 to $3. All the remaining States are in the $1 to $2 group.

The percentage that taxes take of net rent before taxes are deducted is of more significance for comparative purposes than are the per-acre figures which have been summarized. In Figure 6 the States are arranged in order of this percentage. In Michigan taxes averaged 58 per cent and in New Jersey 51 per cent of net rent. Five States are in the group in which taxes average from 30 to 40 per cent of net rent. Four more are in the 25 to 30 per cent group. In one an average of 20 per cent is taken by taxes, and in the two remaining States taxes take between 18 and 20 per cent.

Is it possible from the assembled data to conclude that taxation in any single section of the country is taking a larger proportion of the net income of farm land than in other sections? The four States in which the proportion is highest are Michigan, New Jersey, Ohio, and Indiana. North Dakota and Iowa are not far behind. In other words, the pressure of taxes seems heavier in the North Central States than in the other sections which are represented in Figure 6. The situation in New Jersey is influenced by urban development which often causes high taxation long before a compensating increase in net rent appears.

The data on which the study is based do not supply conclusive evidence sufficient to trace the heavy burden in the North Central States to the single cause either of high taxation or of low income. In each of the States just mentioned, except North Dakota, taxes figured on a per-acre basis are high. It is also a well-known fact that in the North Central States the services that the local governmental units are called upon to supply are greater than in many other sections. In Colorado and North Carolina the percentage of net rent taken by taxes is as high as in some of the North Central States. In Colorado the standard of public services has been kept at a high level for many years, and North Carolina has made heavy expenditures in the last few years to improve its governmental services.

It is unquestionably true that net income from land has been low generally throughout the North Central States for the last eight years. The same statement could apply to agricultural income for the country as a whole, but this region has probably been as unfortunate in this respect as any other. Thus it seems a logical conclusion that both high taxes and low agricultural income have been factors in making the percentage of income taken by taxes high.

Additional confirmation of this conclusion is found in a consideration of the three States in which taxes have taken the smallest percentage of net rent. These States are Arkansas, Missouri, and Virginia. In each a condition exists which makes taxes low as compared with the average of the country. In other words, low taxes here, rather than high income, has kept the ratio between tax and income low.

No simple average of the data presented in Figure 6 is in any sense significant. It is possible to say that in half of these States taxes took from 25 to 35 per cent of the net income of rented farms. In the cases of three States the percentage was lower than this, and in four others it was higher. Hence, on the assumption, which seems on the whole justified, that the States examined are typical of general conditions, it may be estimated that during the period 1922 to 1927 taxes took about 30 per cent of the net income from rented farms.

INCOME AND TAXES OF URBAN PROPERTY

It has been asked whether the relation between income and taxes of farm property differs widely from that which prevails in the case of urban property. The available data permit no conclusive answer to this question, but studies of the subject have been made in nine of the States from which the farm data were secured. A summary of the percentage relation between taxes and net rents on farm and urban properties in these States is contained in Figure 7. The studies have been made to supply the demand for information concerning the taxation of types of property that are not devoted to agriculture.

In five States it took a greater percentage of net rent to pay taxes on farms than to pay taxes on urban property. In the other four States the situation was reversed, taxes on the urban properties taking the greater percentage.

On the basis of these data, no conclusive answer to the question of whether city or farm taxes take the greater proportion of the net return from real estate seems possible. In both cases the percentage that goes to pay taxes is high throughout the country. During the years immediately following the post-war deflation, it seems unques-

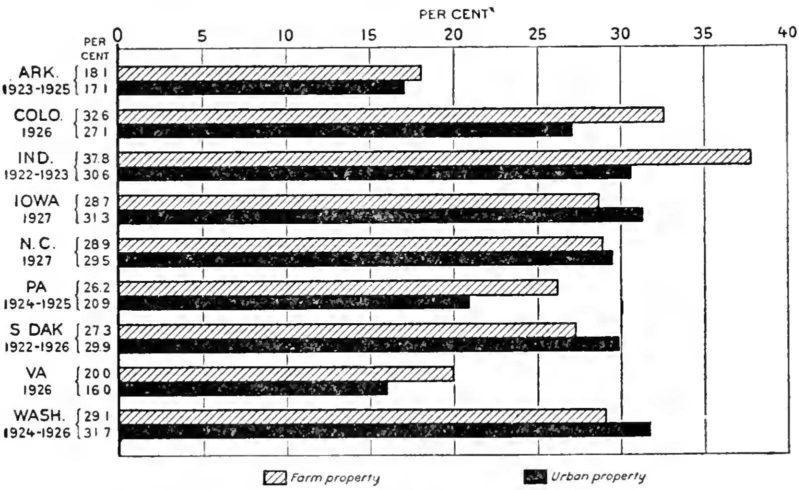

FIGURE 7.—GENERAL PROPERTY TAXES AND NET RENT ON FARM AND URBAN PROPERTY IN NINE STATES SELECTED YEARS, 1922-1927

In five of the nine States taxes take a greater part of the net rent of farm than of urban property. The maximum difference is in Indiana, where taxes on farms were 37.8 per cent of net farm rent and taxes on urban property 30.6 per cent of urban rent. In most of the States the difference is slight.

tioned that farm real estate contributed to public funds a greater proportion of its return than did urban real estate.

Two circumstances tend to explain this situation. Net income on farm property was low, and often nonexistant. Assessed valuations of farm property, on the other hand were at their peak. The fall in market values of farm land was not reflected in a decline in its assessed valuation for several years. The fact that there is in all cases a period of about a year between assessment and payment of taxes makes a lag of one year inevitable. Besides, only half of the States assess farm real estate every year and in many of these States the annual assessment is a formal requirement which results in copying the figures from the previous year's rolls. As a result in many cases farm properties were assessed for several years at a proportion of their actual value which was materially higher than the normal proportion. The effect of this was a high tax contribution at a time when income was exceedingly low.

Too much emphasis should not be placed upon the influence of high farm assessments in causing farms to be taxed at a high proportion of their net yield. Farm taxation is largely local taxation. So far as this local taxation is concerned, it makes no difference whether the average relationship between assessed valuation and true value is high or low. If it is high, the tax rate may be low. If, on the other hand, the relationship is kept low, the tax rate must be high. Low assessment ratios have usually been accompanied by the maximum inequalities of assessment. In other words, it is considered much easier to assess uniformly at a high ratio than at a low rate.

Outside of the local jurisdiction, a difference in the ratio of assessed to true value will tend to transfer part of the taxes from the low-assessed group to the higher groups. But these taxes in most agricultural sections of the country are relatively small in amount and could not account for a large inequality between urban and rural properties. As an examination of the effects of inequalities in assessment forms a later section of this bulletin, detailed attention is not given to the subject here, but it is mentioned as one of the several causes of relatively high taxes for agriculture during the years of the depression.

The comparison which has been made of the taxes and yields of urban and rural properties does not give a satisfactory indication of the relative burdens of taxation on these types of property. From the point of view of current income to the owner of rented land, the comparison is exceedingly important. Examination indicates that both types of property pay high proportions of their net yields in taxes and that on the basis of the few States for which figures are available, farm property seems to pay a slightly greater proportion.

Too much importance should not be attached to the meager conclusions that may be drawn from the comparative data that have been presented. Urban and rural taxes are, in part, different things. That is, the taxpayer in the city is purchasing, through his tax payments, types of services that are different from those paid for in rural tax payments. The city government provides fire and police protection. It maintains a school system which may be no better in its individual units than are the rural schools, but which enables pupils to carry their education further and provides a greater variety of training and more elaborate equipment. The streets maintained by city taxes are of a higher grade and are usually kept in better condition than are roads in rural sections. Street cleaning and lighting are city services that rarely have rural counterparts. Thus, it is apparent that the things for which city taxes are paid are much more extensive than the things which the rural property owner purchases through his tax payments.

In further qualifying the conclusions which might be drawn from a hasty consideration of the data from city and country, it should be recalled that although the services supplied by governmental units are much greater in the cities, the relatively inferior rural services may be provided at a greater unit cost to the taxpayers. No detailed consideration of this is possible at present. It is mentioned merely to suggest another direction in which it is necessary to look before finding the data that are essential to a complete consideration of the subject.

Another problem relating to a comparison of the relative weight of taxation deserves attention. The payment of taxes into the public treasury by an individual or corporation is in itself no indication of the amount which that individual or corporation actually contributes. An enumeration of direct contributions alone necessarily overlooks the possibility that the one who pays the tax may be able to add it to the price of goods or services that he sells or leases, or to subtract it from payments that he makes to others. In other words, he may be able to shift the tax on to some one else. The possibility of such shifting as applied to various taxes and different types of property is considered later.

INCOME AND TAXES OF OWNER-OPERATED FARMS

In a consideration of the income and taxation of farms that are operated by their owners, it must be kept in mind that the income figures are of a different nature from those which have been used in the preceding part of this bulletin. The rent that a tenant pays to his landlord is on an average a close approximation of the ability of the land to produce income. It is income from property rather than from labor. No similar figure for the owner-operated farm can be computed except on the basis of certain assumptions. The description of the methods by which the income of farmers who own and operate their farms is computed will indicate what these assumptions are. Data are presented for the country as a whole and for certain States in which a large body of data has been secured.

THE UNITED STATES AS A WHOLE

Figures relating to the net returns from owner-operated farms have been gathered on a nation-wide basis since 1922. They are obtained through questionnaires sent out each year, and are subject to the limitations that govern complicated data assembled in this way. As their general nature and accuracy have been discussed in detail elsewhere,[15] it is necessary here only to describe the use made of the figures comparing them with taxes paid on each farm. There is added to the difference between receipts and cash outlay (except taxes) the increase in the value of the inventory of personal property. This gives a figure which may be termed the net returns before deducting taxes. Two noncash items are then considered. The value of food produced and used on the farm—a receipt item—is added to the net returns; then the value of family labor, including that of the owner, is subtracted from this sum. The remainder is termed net return before deducting taxes and is compared with the tax figure.

Taxes include small amounts paid on household goods and on a few other items that are not a part of the business property of the farm. These amounts are so small that their inclusion has no material effect on the data.

The net return is a current-income figure. It does not take into account the changes in the capital value of the farm real estate from year to year although inventory changes in personal property are included. There is the further fact that no account is taken of interest payments. In other words, the owner of the farm is assumed to be a full owner. Since the tax figure is based on the whole property

[15] Especially in Crops and Markets (17).

of the farm whether fully owned or merely purchased with borrowed money, it seems proper to leave interest payments out of consideration.

Table 23 contains figures of the net return on reporting farms for the country as a whole and for the different geographic divisions. This net return, is the return on the property of the farm, plus any return which may go to the farm operator as payment for his services as business manager. Taxes per farm are compared with the net returns per farm for each of the years from 1922 to 1927, and the percentage relationships of taxes to net returns are computed.

TABLE 23.—*Net returns*[1] *and taxes on owner-operated farms, 1922–1927*

Geographic division	1922				1923			
	Farms reporting	Net returns per farm before deducting taxes	Taxes per farm	Percentage relationship taxes to net returns	Farms reporting	Net returns per farm before deducting taxes	Taxes per farm	Percentage relationship taxes to net returns
	Number	*Dollars*	*Dollars*	*Per cent*	*Number*	*Dollars*	*Dollars*	*Per cent*
North Atlantic	648	427	146	34.2	1,800	520	160	30.8
South Atlantic	803	572	91	15.9	2,131	490	110	22.4
East North Central	1,274	655	210	32.1	3,395	620	220	35.5
West North Central	1,395	879	211	24.0	3,817	680	240	35.3
South Central	1,282	670	111	16.6	3,320	610	140	23.0
Western	692	606	270	44.6	1,720	810	270	33.3
United States	6,094	669	174	26.0	16,183	605	190	31.4
	1924				1925			
North Atlantic	1,761	516	167	32.4	1,789	857	164	19.1
South Atlantic	1,990	581	122	21.0	1,915	540	119	22.0
East North Central	2,808	830	230	27.7	3,067	1,006	223	22.2
West North Central	3,398	1,067	239	22.4	3,402	1,256	246	19.6
South Central	3,412	947	138	14.6	3,434	665	122	18.3
Western	1,734	1,038	254	24.5	1,725	1,573	271	17.2
United States	15,103	874	192	22.0	15,330	969	191	19.7
	1926				1927			
North Atlantic	1,436	685	171	25.0	1,477	847	169	20.0
South Atlantic	1,761	505	122	24.2	1,837	747	111	14.9
East North Central	2,591	789	208	26.4	2,560	725	213	29.4
West North Central	2,969	912	245	26.9	3,129	1,240	235	19.0
South Central	3,269	831	121	14.5	3,418	850	119	14.0
Western	1,446	1,207	240	19.9	1,438	1,647	245	14.9
United States	13,475	819	183	22.3	13,859	974	180	18.5

Computed from reports of farm returns (*17*).

[1] Average gross cash receipts from sales, plus the value of food produced and used on the farm, plus change in inventory of personal property, minus average current cash expenses, minus the estimate value of family labor including that of the owner. The following items are not included: Interest paid, expenditures for farm improvements, and estimated change in the value of real estate during the year.

For the United States as a whole, the greatest proportion of net returns paid as taxes during the 6-year period was collected in 1923, when the percentage amounted to 31. There was a large increase in net return the following year, and taxes amounted to 22 per cent of net return. Since 1924 the percentage has alternately fallen and risen. It was 20 in 1925, 22 in 1926, and 18.5 in 1927, when the average net return was the highest for any year of the period and taxes were lower than in any year since 1922.[16] Figure 8 contains comparison of the average return and tax figures per farm reported for the United States and of the percentage of net return taken by taxes for each of the six years.

It is unnecessary to describe in detail the figures for each of the geographic divisions. Figure 9 indicates the amount taken by taxes in each of them each year. In relation to farm income this amount has been highest in the East North Central States. It has been lowest in the South Central States. The other regions, starting with those in which the percentage has been lowest, rank as follows: South Atlantic, Western, and West North Central and North Atlantic practically together. No attempt can be made here to examine in detail the reasons for the differences between regions. It will be noted in passing, however, that those sections where the percentage taken

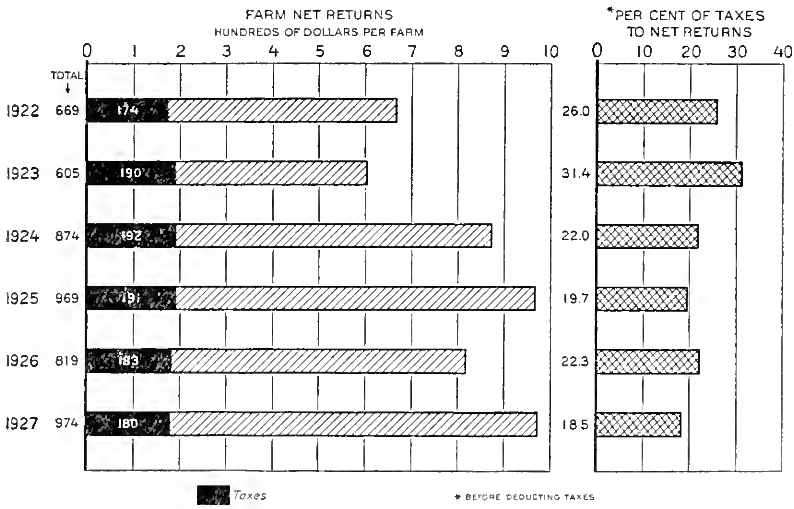

FIGURE 8.—FARM NET RETURNS AND TAXES ON OWNER-OPERATOR FARMS IN THE UNITED STATES, 1922-1927

The average net return per farm was highest in 1927 and lowest in 1923. Taxes averaged highest in 1924. The percentage relationship of taxes to net return was highest in 1923 and lowest in 1927. The change from 1923 to 1927 was largely due to the improvement in farm returns rather than to a drastic reduction in taxes.

by taxes has been consistently lowest are in general the ones where a lower quantity and quality of governmental services (that is, less improved roads and short school sessions with poorly trained teachers) have been supplied than in other parts of the country. This does not apply to every State in each of these groups, but on the whole it seems a fair description of the situation.

The net-return figures with which taxes have been compared is to a certain extent based on two noncash items, food produced and used on the farm and the value of family labor. The values given to these items are estimates and may be less accurate than are the values placed on the cash items and on the increase in the inventory of personal property. For this reason, Table 24 is given, to compare by years and regions the percentage of the net returns (that is receipts

[16] The decline in the tax per farm is undoubtedly due to a decrease in the size of farms reported rather than to a decline in farm taxes.

plus increase in the inventory of personal property minus cash outlay) taken by taxes. This is a comparison of taxes with a composite cash income composed of the current labor income of the farm owner and his family, the return from the farmer's managerial ability, and the return from the property of the farm. The percentage relationship is lower than that which appears in the comparison of taxes and net return, but there is nothing in it which is markedly different from the results already described.

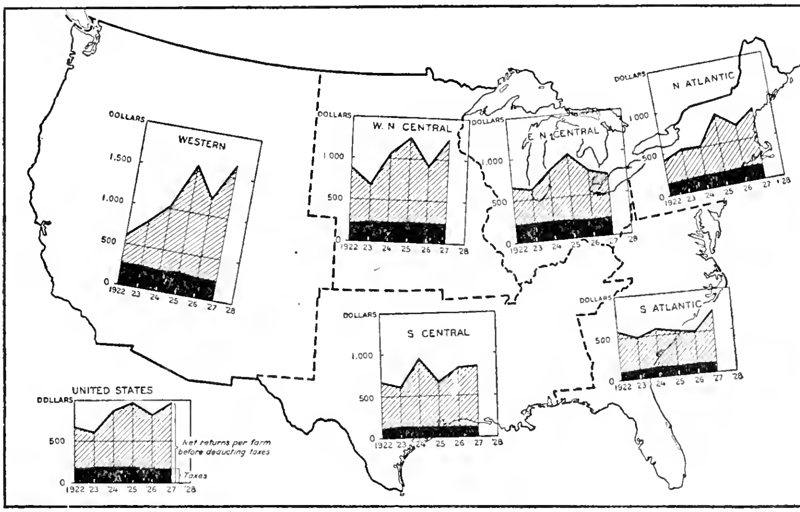

FIGURE 9.—FARM RETURN AND TAXES ON OWNER-OPERATED FARMS, BY REGIONS, 1922-1927

The average farm returns which include in their computation noncash items such as the increase in the value of the inventory of personal property, the value of food produced and used on the farm, and the value of the labor of the farm family including that of the operator, increased from 1922 to 1927 in every section of the country. Average taxes were reported higher in 1927 than in 1922 in every region except the Western States.

TABLE 24.—*Percentage relationship of taxes and net returns (receipts plus inventory increases of personal property minus cash outlays) on owner-operated farms, 1922–1927*

Geographic division	1922	1923	1924	1925	1926	1927
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
North Atlantic	14.5	13.0	14.0	10.8	12.8	11.3
South Atlantic	12.7	12.9	15.7	16.2	17.7	11.9
East North Central	18.5	17.6	16.6	14.0	15.1	16.4
West North Central	14.6	17.8	12.6	12.8	15.6	12.5
South Central	13.1	13.6	11.5	12.9	11.1	10.8
Western	21.5	17.1	14.4	11.7	12.4	10.1
United States	15.9	15.7	13.7	12.8	13.9	12.2

Computed from reports of farm returns (*17*).

STUDIES IN INDIVIDUAL STATES

Investigations of the relationships between the net return and taxes on owner-operated farm land have been a part of the tax studies made in several States. A summary of the investigations made in Arkansas, Iowa, Massachusetts, North Carolina, and Pennsylvania will give an idea of conditions in several widely separated portions of the country.

The same qualifications that applied to the figures that were secured for the country as a whole must be kept in mind in considering this State material. A further caution in its use relates to the fact that the methods of securing the data and the exact nature of the income referred to were not uniform among the States.

ARKANSAS

Figures for the State of Arkansas have been gathered by the questionnaire method which is used in collecting the material for the country as a whole (*1, p. 10*). As the same deductions from gross income have been made, no further description of the method used is necessary. Table 25 summarizes these figures for the years 1922 to 1926. There is a wide variation in the number and size of farms as well as in the net return and tax figures. For this reason, the changes in the net returns from year to year may be as strongly influenced by the changes in the sample as by the changes in the economic conditions of the farmers. For the period as a whole, however, the sample is probably sufficient to indicate general conditions. Taxes are shown to take 14 per cent of the net return on farm property plus the return received for the managerial ability exercised by the farmer. Net returns averaged $577 per farm and taxes $82.

TABLE 25.—*Taxes and net returns on selected owner-operated farms in Arkansas, 1922–1926*

Year	Farms	Acres per farm	Net returns per farm before deducting taxes	Taxes per farm	Percentage relationship taxes to net returns
	Number	*Number*	*Dollars*	*Dollars*	*Per cent*
1922	186	141	445	55	12.4
1923	495	174	333	75	22.5
1924	447	196	754	119	15.7
1925	383	186	739	93	12.6
1926	618	156	613	67	10.9
Average	426	171	577	82	14.2

Arkansas Agr. Expt. Sta. Bul. 223 (*1, p. 10*).
Simple averages and percentages computed from totals and not from derived per-farm figures.

IOWA

The data presented for Iowa farms operated by their owners have been computed from farm management surveys. (*3, p. 56–58*). The method of computation makes it possible to present figures subject to the same interpretation as those presented for the country as a whole and for Arkansas, although the basic data were derived in different manner. The Iowa figures are of particular value in that they included data collected for the years 1913–1916 as well as for more recent years.

Table 26 indicates that for the period 1913 to 1916 taxes took less than 5 cents of every dollar of net return from farm property and from the business ability of the farm operator. In 1918 taxes took only a slightly greater amount, 5½ cents. In the post-war period, 1921 to 1923, the situation had so changed that taxes took nearly 22 cents of every dollar, and on 119 farms for which figures are available in 1927 taxes took 32 cents of every dollar of return. The table shows that net returns from 1913–1916 to 1921–1923 per farm have decreased 50 per cent or more whereas taxes have increased 120 per cent.

TABLE 26.—*Taxes and net return on selected owner-operated farms in Iowa, 1913–1916, 1918, 1921–1923, and 1927*

Year	Farms	Acres per farm	Net returns per farm before deducting taxes	Taxes per farm	Percentage relationship taxes to net income
	Number	*Number*	*Dollars*	*Dollars*	*Per cent*
1913	303	185	3, 047	123	4. 0
1914	168	153	2, 100	116	5. 5
1915	248	192	2, 424	148	6. 1
1916	74	158	3, 101	122	3. 9
Weighted average	[1] 793	178	2, 657	129	4. 9
1918	168	197	3, 086	170	5. 5
1921	109	195	646	336	52. 0
1922	94	179	1, 897	266	14. 0
1923	194	153	1, 396	265	19. 0
Weighted average	[1] 397	171	1, 309	285	21. 8
1927	119	200	957	307	32. 1

Iowa Agr. Col., Ext. Bul. 150 (*3, p. 56*).
(Data recomputed.)

[1] Aggregate for period.

The figures quoted differ somewhat from those appearing in the Iowa bulletin. The difference is accounted for by the omission here of an allowance for house rent in the income received from the farm. Other data used in this section, except the Pennsylvania figures, do not take into account the return from the farm as a residence. In order to make the figures comparable, this has been omitted in the Iowa table. Although the original Iowa figures took into account income received from the farm as a residence, they did not consider taxes paid on the residential value of the farm, all taxes being charged against the farm as a business.

MASSACHUSETTS

Farm-income figures available from Massachusetts include returns to the operators for wages as well as management along with returns on the farm property (*21, p. 112–113*). To make these figures comparable with the others which are being considered, an arbitrary reduction has been made, based on the wages paid hired farm labor in the State in the years concerned. This deduction amounted to $765 in 1920, $603 in 1921, $612 in 1922, and $720 in 1923.[17]

The figures in Table 27 represent a farm-income computation which includes return to the operator for wages and management, and the return on his property, minus an operator labor figure estimated as has been indicated. Taxes show relatively little variation from year to year during the period 1920 to 1923. The change in the percentage of net return taken by taxes was caused by the excessive variation in the net return figure, which, in 1921 was not sufficient to pay taxes and which in 1923 had risen sufficiently high to make taxes amount to about one-sixth of the net return.

[17] The figures are based on the assumption that the average farmer is steadily employed by the work on his farm for the equivalvent of nine months of the year.

TABLE 27.—*Taxes and net returns on selected owner-operated farms in Massachusetts, 1920–1923*

Section of State and year	Farms	Net returns per farm before deducting taxes	Taxes per farm	Percentage relationship taxes to net return
Western Massachusetts:	*Number*	*Dollars*	*Dollars*	*Per cent*
1922	93	433	136	31.4
1923	72	670	131	19.6
Average	82	552	134	24.3
Middlesex and Berkshire Counties:				
1920	143	597	185	31.0
1921	145	125	172	137.6
1922	134	753	181	24.0
1923	135	1,128	183	16.2
Average	139	651	180	27.6

NORTH CAROLINA

Data from North Carolina have been provided by a farm-income survey which included an analysis of the 1927 farm business of 1,156 farmers (*16, p. 46-203*). For purposes of the survey, the State was divided into four districts and within each of these districts reports were secured from farmers in two or more typical localities. As a result there is available from 12 localities in the State of North Carolina a supply of material which gives for the single year 1927 a more adequate description of the financial condition of the farmer who owns and operates his farm than is available for any other State. The fact that the data are so extensive makes them worthy of more detailed treatment than has been given to those from the other States.

Income figures computed on a number of different bases were presented in the published North Carolina report. For purposes of this study, only the ones calculated on approximately the same basis as those used in the studies for the other States and for the United States as a whole are considered. The figures in Table 28 were computed by including among the gross receipts not only the proceeds from the sale of all products from the farm, inventory increases, and the value of the family living obtained from the farm but also receipts from work done off the farm, and the residential value of the farmhouse. The latter of these items was originally included in the Iowa study described on page 38. The comment made there also applies here. There seems little justification for including the value of work done off the farm as an item of receipts in a comparison of farm receipts and farm taxes. To avoid too great change of the material, they are presented in Table 28 in the form in which they were published in the North Carolina report; that is, including receipts for work done off the farm and an arbitrary allowance for the residential value of the farm and the farmhouse.

The figures have been recomputed for the State as a whole and, omitting these two items from receipts, the average net return becomes $307 per farm. Comparing this with taxes of $103 per farm, a revised figure of the percentage of net return taken by taxes amounting to 33.5 is obtained.

TABLE 28.—*Taxes and net returns on selected owner-operated farms in North Carolina, 1927* [1]

Region and area	Farms	Acres per farm	Net return per farm before deducting taxes	Taxes per farm	Percentage relationship taxes to net return
	Number	*Number*	*Dollars*	*Dollars*	*Per cent*
Mountain	281	123	−111	82	---------
Jackson	120	101	−90	67	---------
McDowell	64	141	−117	64	---------
Ashe	97	138	−133	112	---------
Piedmont	311	109	200	70	35.0
Catawba	99	103	27	75	277.8
Davidson	121	92	−36	57	---------
Person	91	139	703	83	11.8
Coastal plain	335	160	1,297	147	11.3
Moore Peach	41	335	5,099	258	5.1
Moore	51	129	420	83	19.8
Cumberland	108	141	415	115	27.7
Lenoir	135	135	1,179	163	13.8
Tidewater	229	150	451	108	23.9
Pender	134	166	191	84	44.0
Chowar	95	127	817	141	17.3
Total or average	1,156	135	492	103	20.9

Adapted from the report of the Tax Commission of North Carolina (*16*).

[1] Net returns in this case includes earnings for work off the farm and an allowance for the rental value of the farm house as a residence, as well as the returns on farm property and on the business enterprise of the operator.

Table 28 illustrates the extreme variations between one locality of the State and another. Four of the localities did not have gross receipts equal to the necessary deductions even before taxes were paid. A fifth area did not have a net return sufficiently high to pay taxes. Pender County, in the Tidewater, reported that taxes were taking 44 per cent of net returns and Cumberland in the coastal plain reported that 28 per cent was taken by taxes. At the other extreme was the Moore County peach territory where taxes were only 5 per cent of net returns. In the remaining localities taxes were between 10 and 20 per cent of net returns, including earnings for work off the farm and an allowance for house rent.

The great variations among individual farms of North Carolina in the percentage of net return taken by taxes is illustrated by Figure 10. For 12 per cent of the farms yielding a net return in 1927, taxes were equal to or greater than this return. One-quarter of the farms yielding a net return paid 50 per cent or more of their net return in taxes and 45 per cent of them paid 20 per cent or more.

Figure 10 and this description of the situation deal only with those farms that yielded some net return to their owners before taxes were paid. Such farms comprise only 678 of the total of 1,156 from which data were secured. In other words, only 59 per cent of the farms in 1927 yielded a net return before taxes were deducted and in the cases of only 51 per cent of them was there enough net return to pay taxes. Contrasted with farms on which taxes took all of the net return are the 28 per cent on which taxes took 10 per cent or less of the net return and 9.5 per cent on which taxes took 5 per cent or less.

Emphasis is placed on this variation from the average condition in North Carolina because it is a situation which had been found to exist in every State in which comprehensive data have been secured and which doubtless exists in all the States. The average percentage of net return paid in taxes is high enough, but it fails to call attention to the real difficulties of the situation. They are found in an examination of conditions affecting those who pay amounts far above the average.

There is no simple remedy for the situation. Deficient income rather than high taxes frequently is the cause, and the remedy for low incomes is far beyond the scope of this study. Suggestions of ways of remedying the tax factor in the situation appear in the concluding section of this bulletin.

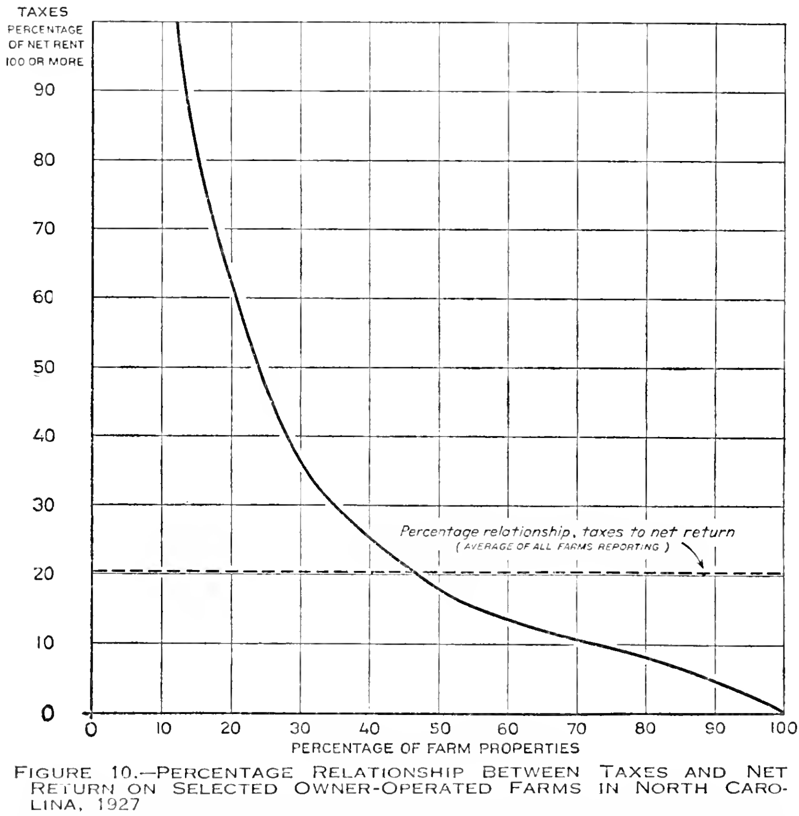

FIGURE 10.—PERCENTAGE RELATIONSHIP BETWEEN TAXES AND NET RETURN ON SELECTED OWNER-OPERATED FARMS IN NORTH CAROLINA, 1927

Farms that yielded no net return before taxes were deducted have been excluded from this comparison. Such farms comprised 59 per cent of the total number from which reports were received. Of the remaining farms, 12 per cent paid in taxes all of what would otherwise have been net return, and 21 per cent paid one-half or more of their net return in taxes. At the other extreme were 28 per cent of these farms, which paid in taxes 10 per cent or less of their net return.

PENNSYLVANIA

Data from Pennsylvania, which are presented in Table 29, require little detailed explanation (*19, p. 7–43*). They are derived from farm survey studies made for the years 1924 and 1925. Net return is figured on the same basis as in the other studies of owner-operator net return, with the single exception that the receipts figures include an allowance for the estimated value of the house rent. No attempt is made to allocate a portion of the tax payment to apply to this house-rent factor, all of the taxes being charged to the farm business.

TABLE 29.—*Taxes and net returns on selected owner-operated farms, Pennsylvania, 1924–25*

County	Farms	Net returns per farm before deducting taxes	Taxes per farm	Percentage relationship taxes to net return
	Number	*Dollars*	*Dollars*	*Per cent*
Crawford	40	−33	117	----------
Lancaster	69	1,006	168	16.7
Lebanon	105	454	154	33.9
Warren	43	90	92	102.2
Westmoreland	48	234	147	62.8
Wyoming	27	633	152	24.0
Total or average	332	446	143	32.1

The percentage of net return taken by taxes varied from 17 in Lancaster County, where the farms for which data were secured were above the average for the county, to 102 in Warren County. No percentage figure for Crawford County can be quoted as the average return for that county indicated a loss before taxes were paid. The average percentage relation of taxes to net return for the State was 32. This is probably a conservative figure, for, although different types of the agriculture of the State influence it, the farms representing several of the sections are above the average.

SUMMARY OF THE STATE STUDIES

No attempt will be made to combine the results of the State studies into an average figure. The number of them is so small that such a figure would be representative of nothing more than an average of conditions in five widely separated States. The fact that an analysis of figures gathered for the country as a whole has already been made renders any further averaging unnecessary.

It should be pointed out, however, that to a certain extent these State figures are consistent with those which were secured from rented farms and which are summarized on pages 29–31. The figures for rented farms indicated that taxes were low as compared with rent in certain Southern States, among which was Arkansas. This State is the lowest of the five considered in the study of the relationship between taxes and net returns on owner-operated land. Iowa, which stood close to the average in the rented-land study, occupies about the same place in the owner-operator study. North Carolina and Pennsylvania each show a somewhat higher percentage of net return than of net rent taken by taxes.

It seems probable that, if data for owner-operated farms in other States were available, these States would be found in approximately the same place in each of the studies. In other words, there is no indication from the available data that the results of the two portions of the study are inconsistent. They concern different types of income, but the conditions which make one type high should influence the other in the same direction. There is no indication that taxes are greatly different on land utilized by the two tenure groups. Hence, differences in the percentage relation of taxes to net rent on land will tend to vary in the same general direction as differences in the relationship of taxes to net return on owner-operated land.

ASSESSED VALUATION AND SALES VALUE OF FARM REAL ESTATE

It has frequently been remarked that one of the chief difficulties connected with the general property tax relates to the assessment of property. In the first place, there are large amounts of property with tax-paying ability that do not appear on the assessment rolls. Intangible property, to a large extent, escapes all taxes, particularly in those States in which the legal attempt is made to tax it at the same rate that applies to other property. Even in the case of tangible property much escapes the assessor's attention. Household goods are commonly assessed only on the most arbitrary basis. Valuable jewelry almost always escapes assessment.

But in the well-conducted assessment district, real estate has little chance of not being noticed by the assessor. The placing of a value on such property is far from an easy matter, and many inequalities arise from this source. Special investigations to determine the relation between assessed valuation and sales values of farm property have been made in Delaware (*6*), Kansas, and Oregon. Data have been accumulated as a part of other investigations in Arkansas, Colorado, Iowa, Massachusetts, New Jersey, New York, Ohio, Pennsylvania, and Virginia. No attempt is made to examine in detail the results of these studies, but data drawn from certain of them will be used to illustrate the various points considered.

It is necessary in the first place to understand what assessed valuation means. Little attention need to be paid to its legal description. Although certain variations occur from State to State, the general import of such definitions is the same—sales value at a sale which is not forced on either side. In a few States consideration is to be paid to the earning capacity of land, but this is only one feature among several which are to determine the valuation. In some cases the law further requires that all property or certain classes of property be assessed at some percentage other than 100 of sales value. All farm real estate, however, in any single State is to be assessed on a single basis.

Every 10 years the Bureau of the Census attempts to estimate the percentage of actual value at which the real property in each State is assessed. The estimate is subject to a wide margin of error, but the variations in percentage among the various States are significant. No State in 1922 was reported as being successful in assessing on a 100 per cent basis. The District of Columbia, where assessments were estimated at 91 per cent of true value, came closest to this. States in which the percentage was from 80 to 90 per cent were Arizona, Indiana, Michigan, New York, Rhode Island, South Dakota, and Wisconsin. At the other extreme were Florida and South Carolina, with 20 per cent assessment records.

Such variations would be of only slight importance if there were uniformity of assessment within each of the States. It makes little difference to the taxpayer whether his assessment is high and his tax rate low or his assessment low and his tax rate high so long as he is called upon to pay a certain definite amount for the services supplied by the governmental units. Difficulties arise when one taxpayer has his land assessed at a high proportion of its value and finds his neighbor's land in the same tax district to be assessed at a low percentage. Similarly inequalities between taxing districts are produced by variations in their ratios of assessment to value.

A brief description of certain aspects of the results of several of the investigations indicates the importance of these and other inequalities.

In an investigation in Kansas (*8*), which contained data for the years 1913 to 1922, inclusive, the following types of inequalities arising from a lack of uniform assessment were examined: (1) Inequalities among individual parcels of farm real estate; (2) inequalities among individual parcels of city real estate; (3) inequalities between large and small farm properties; (4) inequalities among townships; and (5) inequalities among counties.

Inequalities among individual parcels of farm real estate were more important than any of the other types, both because the inequalities in themselves were greater and because they affected a larger proportion of the tax levy than did the others. The other two major sources of inequality were the variation among individual parcels of city real estate and that between large and small parcels of farm real estate.

Figure 11 illustrates the variation of 1,141 parcels of Kansas farm real estate in 1921–22 from the average percentage of their assessed valuation to their sales value. The vertical axis of this figure represents the percentage of assessed valuations in terms of sales values and the horizontal axis the precentage of the total number of properties assessed at or below the indicated levels. If the properties had all been assessed uniformly at any one percentage of their sales value, they would have been represented by a horizontal line. The deviation from the horizontal of the line representing the actual situation is an indication of the extent to which there is inequality in individual assessments.

The situation in Kansas in 1921–22 may be compared with that in Iowa in 1927 (*3, p. 11–24*). The Iowa situation is illustrated by Figure 12, which is constructed in a manner similar to that used in Figure 11. The average percentage of assessed valuation in terms of sales value was lower in Iowa than in Kansas. This in itself is of little significance, the important factor being the variation of the individual assessments from the average. The Kansas figure shows a greater variation from the average than does the Iowa figure. The fact that the average assessment in Kansas is higher makes the variation seem greater than it would if the averages were the same, but even taking this into consideration it is evident that the variation from the average was greater in Kansas than in Iowa.[18]

These cases are taken as examples of the general situation. No comparison of the efficiency of assessment in the States concerned can be made from data drawn from years when conditions were so entirely different. No attempt will be made to illustrate this type of inequality from data secured in other States. Wherever studies of the subject have been made much the same situation has been found.

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[18] The coefficient of variation of the Iowa cases is 26 per cent, whereas that of those in Kansas is 31 per cent.

The effect of these inequalities in assessment among individual pieces of real estate deserves close attention. Real-estate taxation is primarily local in character. In 1922, for the country as a whole, the share of the general property tax going to county and local units amounted to 90 per cent of the total tax levy. It is within these minor civil divisions that inequality is of the greatest importance. If it were possible to have equality of assessment within the counties, the

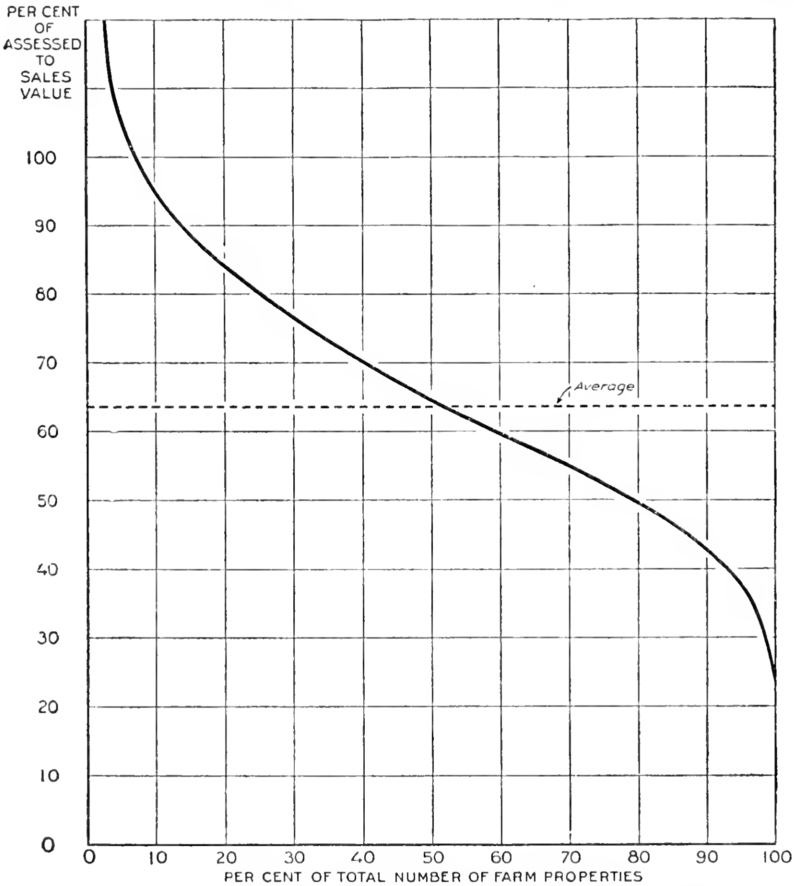

FIGURE 11.—DISTRIBUTION ON THE BASIS OF THE PERCENTAGE RELATIONSHIP OF ASSESSED VALUATION TO SALES VALUE, 1921-22, OF 1,141 PIECES OF FARM REAL ESTATE IN KANSAS

Ten per cent of the properties were assessed at 95 per cent or more of their sales value. Another 10 per cent were assessed at less than 45 per cent of their sales value. The upper 30 per cent of the properties were assessed at 75 per cent or more of the sales value and the lower 30 per cent at 55 per cent or less.

intercounty inequalities, to which reference will be made later, would make the assessment of real estate only slightly inequitable.

An illustration of the situation may be taken from a study made in Oregon (7). As a result of the inequalities among individual assessments it was found that the half of the real estate of Oregon, which was assessed the highest relative to its sales value, paid two-thirds of the total taxes on real estate, whereas the half of the real estate which was assessed the lowest relative to its sales value paid only one-third of the taxes. In other words, the owner of a piece of property falling at the average of the upper assessment group might have to pay $400 in taxes, whereas the owner of another piece which had the same sales value but which was assessed at the average of the lower group would have to pay only $200. The situation in some of the counties in Oregon was better than this, but in others it was considerably worse.

If it could be assumed that the inequalities within the county were eliminated but that the intercounty lack of uniformity would remain, the following situation would exist. Using the farms that have just been mentioned as examples, it will be assumed that they are in dif-

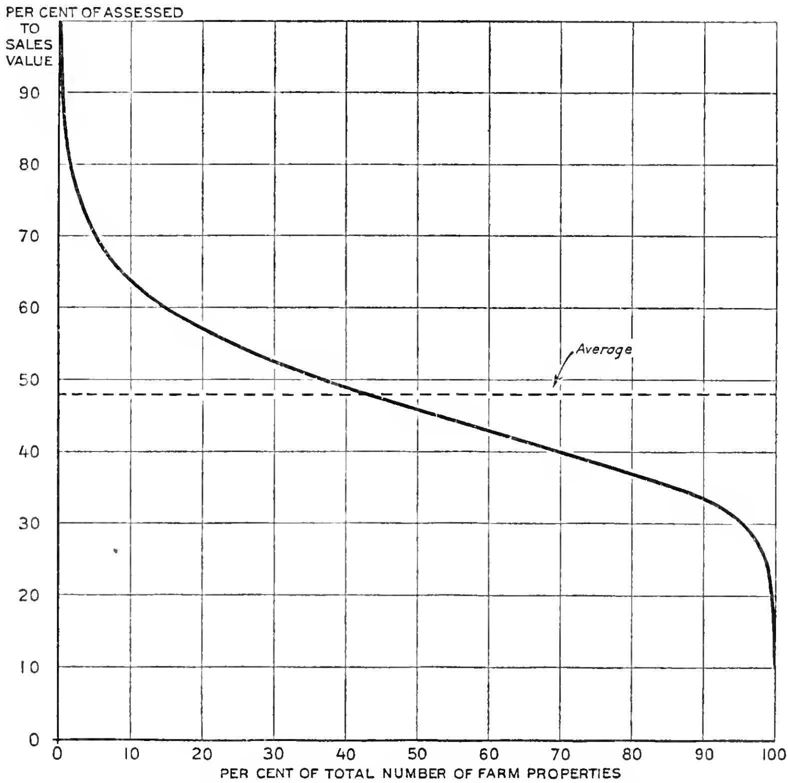

FIGURE 12.—DISTRIBUTION ON THE BASIS OF THE PERCENTAGE RELATIONSHIP OF ASSESSED VALUATION TO SALES VALUE OF 2,150 PIECES OF FARM REAL ESTATE IN IOWA, 1927

The upper 10 per cent of the total number of properties examined were assessed at 64 per cent or more of their sales value, and the lower 10 per cent were assessed at 33 per cent or less. The upper 30 per cent were assessed at 53 per cent or more and the lower 30 per cent at 40 per cent or less. The curve describing the distribution is closer to the horizontal line indicating the average than in the case of Figure 11.

ferent counties, one of which is assessed at the average of the upper assessment group and the other at the average of the lower group. The tax rates within the counties are assumed to be the same. What inequality is involved in the State taxes levied on the two properties? Their combined taxes amount to $600. Ninety per cent of this, using the average for the country as a whole,[19] is collected within the coun-

[19] In Oregon the situation is somewhat different, about 80 per cent being collected by the county and local units. Applying this percentage to the example, the two properties described would pay $320 and $280 respectively.

ties, where assessments are assumed to be equitable. This takes care of $540, or $270 each. The other $60 is subject to the intercounty inequality, two-thirds, or $40, being paid by one piece of property, and one-third, or $20, being paid by the other. The first property would have a total tax of $310 and the second a tax of $290.

Emphasis is placed on these examples of the relative importance of inequalities within the local units and among the counties since many of the State boards of equalization that attempt to remove inequalities function only among the larger units. Their work is necessary and does relieve to a small extent certain of the inequalities. But they are able to consider factors that cause only a minor part of the maladjustment of real estate taxes. The major portion of the inequalities lies within the local units and can be remedied only by improvement in the initial assessment.

One further type of inequality, which was described by the Kansas report and which almost every study before or since that particular

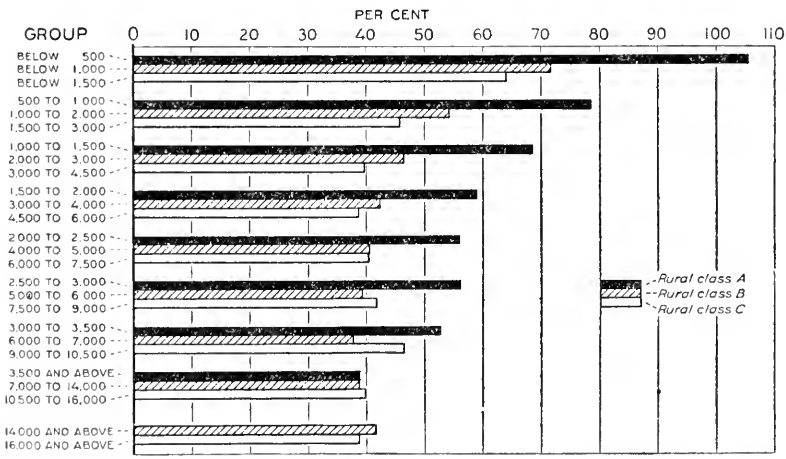

FIGURE 13.—RATIOS OF ASSESSED VALUATIONS TO SALES VALUES OF RURAL REAL PROPERTY IN OREGON, CLASSIFIED ACCORDING TO VALUE GROUPS, 1921-1926

The tendency is for the ratios between assessed valuation and sales value to decline as the value of the properties becomes greater. This tendency is particularly evident in the group of properties that appear in class A, and to a lesser degree it appears in the other groups. [Reproduced from Oreg. Agr. Expt. Sta. Bul. 223, (*7, p. 18*).]

one has brought to light, is a discrimination in relative assessment between properties of low sales value and those of high value namely, between small and large properties. All farms for which data were secured in Kansas were divided into eight value groups based on sales value. The average ratio of assessed valuation to sales value, expressed on a percentage basis, for each of these groups, begininng with the group having the lowest value, was 85.7, 76.7, 72.9, 70, 66.4, 65.3, 62.3, and 58.7. In other words, as the sales value of property increased, the percentage of assessed valuation to sales value decreased.

In Oregon the same situation was found to exist. The counties of that State were divided into three classes on the basis of variations in the average values of farm property. Figure 13 shows the relation between assessed valuation and sales value in the various value groups in each of these classes. Group 1 represents the properties with the lowest sales value in each of the classes. Group 8 in the case of class A and Group 9 in each of the other classes represent the highest sales values. In each of the classes there is a pronounced difference between the ratios of assessment of the four low-value groups and those of the remaining groups.

The tax commission of New York (*15*) has published data relating to sales value and assessed valuations outside of cities and incorporated villages. Table 30 summarizes these figures and points to the same high relative assessment of the lower value groups that has been found in the other States. The New York figures do not relate entirely to farm property. They do, however, describe the conditions prevailing in rural sections of the State. The further fact that the same tendency toward high relative assessments in the lower value groups in incorporated villages in New York State tends to emphasize the importance of this factor in determining the distribution of taxation.

TABLE 30.—*Sales value and assessed valuation of property outside of cities and incorporated villages, New York State, 1915–1925*

Value groups (sales value)	Number of sales	Average sales value	Averaged assessed value	Percentage relationship sales value to assessment
0–$5,000	44, 739	$2, 431	$1, 289	53. 0
$5, 001–$10, 000	11, 833	7, 006	3, 392	48. 4
$10,001–$15,000	2, 830	12, 270	5, 812	47. 4
$15,001–$20,000	940	17, 505	7, 984	45. 6
$20,001–$25,000	334	22, 656	9, 596	42. 4
$25,001–$30,000	195	27, 781	10, 553	38. 0
$30,001–$40,000	155	35, 085	14, 749	42. 0
$40,001–$50,000	72	45, 809	18, 053	39. 4
$50,001–$100,000	76	70, 429	29, 796	42. 3
Over $100,000	22	161, 159	67, 219	41. 7
0–$10,000	56, 572	3, 388	1, 729	51. 0
Over $10,000	4, 624	17, 690	7, 903	44. 7
Total or average	61, 196	4, 469	2, 195	49. 1

Annual report of the State tax commission, (*15, p. 450*). In this table certain groups are consolidated and the averages and percentages recalculated.

A Delaware study, completed at the end of 1928, revealed a similar tendency for the ratio of assessment to sales value to decrease as the value of the property increases (*16*). This tendency was marked in town property in each county of the State and in the farm property of two of the three counties.

Several reasons may be cited for this tendency to assess low-valued property at a higher proportion of its sales value than higher-valued property is assessed. The taxing officials are more familiar with the low-valued property. They are called upon to deal with a greater amount of it, and so it becomes less difficult for them to approximate the sales value. It is necessarily easier to assess a small piece of property. The assessor can inspect it all and he can keep the results of such inspection in his mind. The improvements bulk large on many small properties, and these tend to make the property seem more valuable even though they do not appear as a major influence in the actual values that the assessor places on the tax books in those districts in which improvements and land are assessed separately.

Large properties, on the other hand, are the exception rather than the rule. The inspection of them is more difficult, and the attempt to hold their extent in mind is beyond the ability of many assessors. The large figures that accurate assessment would involve are sufficiently beyond the experience of many assessors to make a low valuation almost inevitable. Then, too, the owner of a large piece of property is more likely to complain of an assessment than is the owner of a small piece. His political influence is frequently great enough to make the assessor hesitate to incur his enmity. A combination of any or all of these factors, together with the underlying lack of a development of scientific methods to apply to the assessment of farm properties, accounts for most of the inconsistencies that arise from relatively high assessment of low-valued properties.

The difference in the average level of assessment among taxing units, although less important than other inequalities of assessment, has attracted much attention. Its effects have been compared with the effects of inequalities among individual properties. It is caused partly by the general lack of equality among individual assessments. Reasons for this have already been considered. Competition among taxing units to escape State or other taxes explains most of the remaining inequalities among units. Each assessor has in mind that other assessors are keeping their valuations down in order to lessen the contribution to the State by the property of their districts. The result that naturally follows is the competitive lowering of the ratio between assessed valuation and sales value.

In concluding the consideration of the effects of the present assessment system on farm property, one particular point needs emphasis. Improvement in methods of assessing individual properties will probably do more toward equalizing the burdens of the general property tax on farm property than will any other change that may reasonably be expected. The general property tax, inequitable as it is in many of its features, will constitute the chief means of raising money to support the agencies of local government for many years to come. It should gradually become of diminished importance, but experience indicates that for many years no new source of revenue will supplant a large part of it. For this reason it will be advantageous to owners of farm real estate to use all possible means to secure more uniform methods of assessment.

In the case of urban property there has been much progress in introducing efficient and scientific methods in the assessors' offices.[20] Although many rural assessors are making use of the best means that they can secure, they find themselves handicapped by the fact that little attention has been given to the scientific determination of what should constitute value for purpose of taxation. More attention needs to be given not only to the basic elements of rural assessment, but it should also be given to the simpler matters of methodology. Maps, current reports of sales, and improved indexes of reports will all furnish means by which improvements can be made. Methods of choosing assessors and their supervision, training, salary, and tenure of office all provide possibilities which should be considered in any attempt to improve assessments.

[20] The studies of Herbert D. Simpson on the assessment of real estate for taxation in Chicago indicate that city conditions may be as unsatisfactory as those in rural communities. The Chicago difficulties were largely political, however, rather than scientific.

It is impossible here to indicate the assessment method that should prevail in each State. Local methods of organization, State history and traditions, and differing basic conditions make generalizations unsatisfactory. No single program of assessment reform could fit the needs of every State. But in every State in which investigations of the subject have been made there is an underlying need for improvement in the assessing process, and it may safely be assumed to exist to a greater or less degree in the other States. Methods of meeting this need will differ. There is a field for experimentation, but the basic fact that assessment of rural real estate is in an unsatisfactory condition needs constant reiteration.

Although it is true that the assessment of other property, particularly of personalty, is in a worse condition, it must be kept in mind that real estate now forms the basis for the support of the functions of local government, and that even if the general property tax does become a less important feature of American taxation, there is no immediate chance that the taxation of real estate will be greatly reduced. Real estate's heavy burden, judged from the point of view of income, supplies further emphasis of the need for an equitable adjustment of assessments. If rural property in a State is paying in taxes, on an average, 30 cents per dollar of income, studies indicate that two adjacent properties, because of inequalities in assessment, may be paying 40 cents and 20 cents, respectively. Under conditions where taxes averaged 8 or 10 cents per dollar of income and where assessment inequalities caused adjacent farms to pay 6 and 12 cents, respectively, an inequitable situation existed, but its effects were of far less consequence than are the present effects of unequal assessment. The remedying of the situation created by inequalities in assessment may well form a major part of every attempt to improve rural tax conditions.

TAXES AND THE VALUE OF FARM LAND

In presenting certain data regarding the relationship between taxes and farm values, emphasis will be placed on two sorts of material, each of which is in part derived from the 1925 Census of Agriculture. The first of this material to be examined was secured in connection with the analysis of taxes and cash rents in one or two counties in each of 16 States. The relation between rent and taxes on selected farms in these counties was analyzed in pages 7 to 12. It will be recalled that the size, the value, and certain other data relating to the farms were taken from the census returns, whereas the tax figures were secured from the official records in the counties.

The second type of material to be presented here is computed from the 1925 census and relates exclusively to farms operated by their owners. It consists of a simple comparison of taxes reported on certain of the farms with the value of these farms. Additional data could be secured from certain of the intensive State studies that have been analyzed in earlier portions of this bulletin. But the material from which they are derived is neither as extensive nor in most cases as well adapted to the particular purpose as that here used.

TAXES AND VALUES OF CASH-RENTED FARMS IN 16 STATES

Sixteen States of the North and West are included in the comparison of taxes and farm values which is summarized in Table 31. The figures representing the years 1919 and 1924 were secured in the same manner, and if they are subject to a bias because of the method by which they were compiled, the effects of the bias should be somewhat the same in each case. The value per acre figures that appear in Table 31 were computed by taking from the census schedules the acreage and the value of land and buildings for each rented farm for which tax figures were secured from the official county records. The aggregate tax and value figures for each county were divided by the acreages involved.

TABLE 31.—*General property tax and estimated value of selected rented farms in 16 States, 1919 and 1924*

State and county	Value per acre		Taxes per acre		Percentage relationship taxes to value	
	1919	1924	1919	1924	1919	1924
					Percentage	*Percentage*
California:						
Merced [1]	$221.49	$69.64	$1.63	$0.87	0.74	1.25
Sacramento	184.85	225.67	1.36	4.23	.74	1.87
Colorado:						
Delta [2]	79.02	40.44	.96	.84	1.21	2.08
Otero [1]	187.40	17.47	2.19	.47	1.17	2.69
Idaho:						
Ada [1]	237.84	136.49	2.85	1.77	1.20	1.30
Madison [2]	252.12	126.85	1.76	1.53	.70	1.21
Illinois: Macoupin	127.58	72.19	.64	.72	.50	1.00
Indiana: Tipton	238.63	135.18	1.41	2.22	.59	1.64
Iowa:						
Union	165.83	103.08	.84	1.25	.51	1.21
Story	296.07	163.71	1.37	1.83	.46	1.12
Kansas: Butler	57.01	53.15	.41	.53	.72	1.00
Minnesota: McLeod	136.61	108.36	.85	1.26	.62	1.16
Missouri: Bates	----------	56.71	----------	.48	----------	.85
Nebraska: Wayne	243.31	138.22	.67	.87	.28	.63
New York:						
Delaware	128.57	129.27	.38	.63	1.33	2.15
Niagara	110.31	110.51	.85	1.78	.77	1.61
Ohio: Franklin	194.67	166.03	1.41	1.99	.72	1.20
Oregon: Washington	136.51	105.19	1.64	2.17	1.20	2.06
South Dakota: Moody	206.39	104.95	.77	.81	.37	.77
Utah: Salt Lake	278.13	310.52	2.82	4.82	1.01	1.55
Wisconsin: Dane	154.95	101.36	1.18	1.49	.76	1.47

[1] The types of farm land covered by the 1924 and the 1919 figures for these three counties are sufficiently different to make direct comparison of the value and tax figures misleading.
[2] The number of farms for which reports are available in these counties makes it possible that the changes in the tax figures from 1919 to 1924 are due to changes in the sample rather than changes in actual conditions.

The average value per acre ranged from $17 in Otero County, Colo., to $311 in Salt Lake County, Utah. Particular significance is attached to the comparison of the 1924 average figures with those of 1919. In three counties—Merced in California, Otero in Colorado, and Ada in Idaho—the type of farm covered by the 1924 tax study is sufficiently different from that included in the 1919 study to make a comparison of the figures for the two years misleading. Figures from the other 17 counties in 15 States may properly be compared to determine the change that occurred over the 5-year period. In 13 counties there was a decrease in the average value per acre ranging from 6.8 to 49.7 per cent. In 4 counties there were increases in the values amounting to 0.2, 2, 12, and 22 per cent.

The predominating decrease is exactly what was to be expected. It is mentioned only to assist in explaining the changes that occurred in the percentage relationship of taxes to value. The average tax per acre increased from 1919 to 1924 in 15 of the 17 counties. This increase ranged from 5 to 211 per cent.

The percentage relationships of taxes to value for each of the years in each of the counties are compared in Figure 14. In every case, the 1924 percentage is higher than that of 1919. There was an increase in the number of dollars taken in taxes per $100 of value, ranging from 8 per cent in Ada County in Idaho to 178 per cent in Tipton County in Indiana. The median number of dollars of taxes per $100 of value for the 17 counties amounted in 1919 to 0.73 and in 1924 to 1.25.

In this consideration of the changing relationship of taxes to value one fact needs to be kept firmly in mind. The increase in the number of dollars of taxes per $100 of value is due to two factors, the decline in land values and the increase in taxes. No attempt will be made here to assign to each of these a relative importance. Average figures of decline in value and increase in taxes would tell only part of the story, and their accurate computation is rendered difficult by the problem of weighting. Then it is probable that an interrelationship exists between taxes and value. An increased level of taxation that is expected to be permanent will be reflected in the price that a buyer will offer for land since his return on the land will be reduced by the taxes that he has to pay. It is impossible at present, however, to segregate definitely the effects of the capitalization of taxes from the other factors that have caused land to decline in value since 1919. For these reasons no attempt will be made to attribute a portion of the change in relationship of taxes to value to alterations in either factor of the problem. Both have changed, and the change in their relationship can be explained only by taking into account the many causes that have made taxes rise and land values fall.

TAXES AND VALUES OF OWNER-OPERATED FARMS OF THE UNITED STATES

The data to be presented in the pages that follow have been derived from reports secured from owner-operated farms for the 1925 census of agriculture. All owner operators have not reported this item, but a sufficient number have reported it to give a wide sample of conditions in every State.

In each case in which a tax figure is reported, the farm owner was asked to state the taxes paid on the land and buildings of his farm in the year 1924. As tax payments are definite in their nature and as they tend to be of importance in the consciousness of the average farmer, there seems to be little reason for believing that the tax figures are in general less accurate than the other data secured by the census of agriculture.

Two qualifications should be attached to this statement. In some cases it undoubtedly has been difficult for the farmer to state accurately the amount paid on the land and buildings of his farm as distinct from that paid on his farm as a whole, including personal property with his real estate. To this extent, certain of the figures are estimates, but they are estimates on a far sounder basis than exists for many of the other figures which the census enumerators secure from the farmers.

The second qualification relates to the difficulty that a farmer who owns a large tract and operates only a small part of it may have had in allocating a tax figure to the part operated. In some cases it is probable that the tax figure recorded related to all the land owned

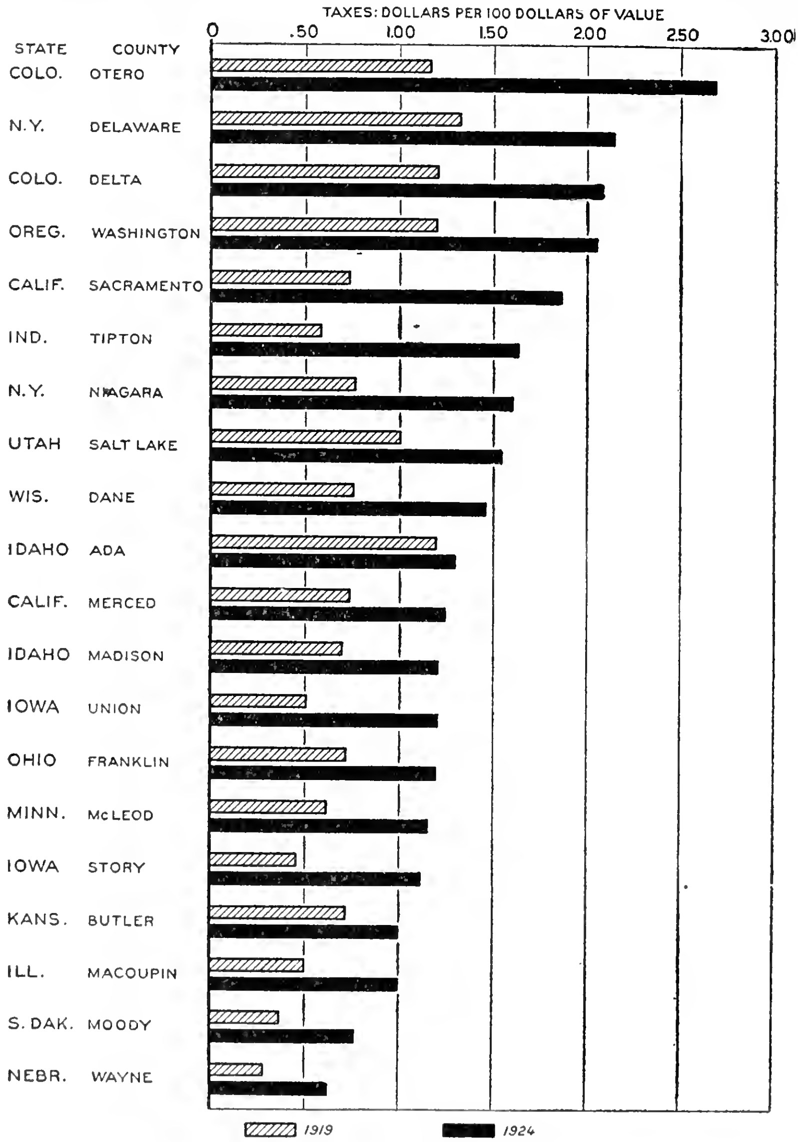

FIGURE 14.—RELATION OF THE GENERAL PROPERTY TAX TO THE ESTIMATED VALUE OF SELECTED CASH-RENTED FARMS IN 15 STATES, 1919 AND 1924

In 1919 taxes per $100 of value were highest among the counties studied on farms in Delaware County, N. Y., where they amounted to $1.33. They were lowest in Wayne County, Nebr., at 28 cents. By 1924, Otero County, Colo., had taxes of $2.69 per $100 of value with Delaware County, N. Y., next to the highest with taxes of $2.15. Wayne County, Nebr., was still lowest with taxes of 62 cents.

and the other data only to the land operated. Although such cases may have been numerous enough in certain of the counties to affect the accuracy of figures which might be computed for these counties, it is highly improbable that their effect in the State aggregates would be sufficient to affect seriously the averages and ratios that will be presented. To guard against serious inaccuracies, the results computed from census returns have been compared with other independently collected data.

A comparison was made with an independently estimated tax per acre figure for each of the States. This figure has been based on reports from a small sample of the farmers of the country and has been used chiefly as an indication of the trend of farm taxes. It is significant that in the case of only seven States—Ohio, Illinois, Kansas, South Carolina, Arkansas, Montana, and Utah—did the per-acre tax figures based on the census returns exceed the per-acre figures of this estimate. In other words, the census figures seem more conservative than the others. For these seven States the taxes computed from census returns were $1.42, $1.20, $0.60, $0.42, $0.41, $0.18, and $0.53 per acre, respectively, and the independently estimated figures were $1.33, $1.17, $0.54, $0.37, $0.32, $0.17, and $0.39. In five of these seven cases, the difference amounted to less than 14 per cent. In the two remaining cases the differences amounted to 28 and 36 per cent, respectively.

In Arkansas, in which the difference is 28 per cent, of two studies made since the original independent estimate, each indicates a tax per acre figure for 1924 amounting to well above the 41 cents computed from census returns. In Utah, in which the difference was 36 per cent, the evidence on which the independent estimate was based was so slight that little reliance can be placed in it. An earlier estimate for the years 1921 and 1922 had placed the per-acre tax figure for that State at 42 cents. It is certainly not impossible that it had increased to 53 cents two or three years later. This would involve an annual increase of from 8 to 10 per cent, which was not unusual during that period.

In the comparison of census and estimated tax figures there was no attempt to do more than show that the census figures for individual States were low as compared with other estimates. It was recognized that the chief criticism which might be made was that the farmers reported too high a tax figure, or rather a tax figure which included payments on something more than the value of the land and buildings which was to be compared with taxes. An analysis of the data indicates that although this defect in the data may apply in scattered individual cases, it probably does not materially increase the average tax figures of the States.

With the understanding that the individual reports are, on an average, accurate enough to deserve consideration, it will be profitable to consider whether they are sufficiently numerous to merit attention. Table 32 compares for each State the number of owner-operated farms for which taxes were reported with the total number of owner-operated farms and with the total number of farms of all tenure groups. For the country as a whole, taxes were reported for 89 per cent of the owner-operated farms and 46 per cent of all farms. The land in these farms for which taxes were reported amounted to 88 per cent of the total land in owner-operated farms and to 40 per cent of all land in farms. For the country as a whole, then, there are reports from nearly 9 out of every 10 owner-operated farms and from 46 of every 100 farms of all tenure classes. It should be emphasized, however, that only the owner-operated farms are included in those reporting tax figures.

TABLE 32.—*Owner-operator farms for which reported taxes for 1924 were compared with total number of owner-operator farms and with all farms*

Geographic division and State	All farms		All full owner-operator farms		Full owner-operator farms for which taxes were reported	
	Number	Land in farms	Number	Land in farms	Number	Land in farms
		Acres		*Acres*		*Acres*
New England	159, 489	15, 857, 927	143, 563	13, 728, 893	135, 831	13, 006, 622
Maine	50, 033	5, 161, 428	47, 249	4, 815, 580	45, 804	4, 676, 285
New Hampshire	21, 065	2, 262, 064	19, 520	2, 033, 519	19, 078	1, 983, 940
Vermont	27, 786	3, 925, 683	24, 047	3, 236, 192	22, 678	3, 030, 014
Massachusetts	33, 454	2, 367, 629	29, 594	1, 942, 118	29, 080	1, 911, 388
Rhode Island	3, 911	309, 013	3, 033	229, 663	2, 987	218, 056
Connecticut	23, 240	1, 832, 110	20, 120	1, 471, 821	16, 204	1, 186, 939
Middle Atlantic	418, 868	37, 490, 939	332, 080	27, 315, 149	298, 220	24, 698, 181
New York	188, 754	19, 269, 926	149, 761	14, 002, 751	143, 520	13, 423, 077
New Jersey	29, 671	1, 924, 545	23, 875	1, 349, 249	19, 345	1, 025, 376
Pennsylvania	200, 443	16, 296, 468	158, 444	11, 963, 149	135, 355	10, 249, 728
East North Central	1, 051, 572	112, 752, 458	667, 737	60, 997, 134	617, 980	56, 766, 960
Ohio	244, 703	22, 219, 248	163, 421	12, 898 522	153, 126	12, 143, 664
Indiana	195, 786	19, 915, 120	114, 378	9, 725, 210	101, 470	8, 679, 667
Illinois	225, 601	30, 731, 947	96, 200	10, 478, 248	86, 412	9, 586, 123
Michigan	192, 327	18, 035, 290	143, 161	12, 030, 278	135, 021	11, 309, 719
Wisconsin	193, 155	21, 850, 853	150, 577	15, 864, 876	141, 951	15, 047, 787
West North Central	1, 111, 314	248, 081, 143	505, 712	87, 122, 918	451, 123	78, 437, 000
Minnesota	188, 231	30, 059, 137	112, 906	14, 963, 215	106, 254	14, 193, 163
Iowa	213, 490	33, 280, 813	92, 705	12, 476, 671	86, 970	11, 861, 378
Missouri	260, 473	32, 641, 893	141, 794	17, 697, 759	118, 663	14, 866, 659
North Dakota	75, 970	34, 327, 410	26, 348	9, 659, 852	22, 526	8, 363, 847
South Dakota	79, 537	32, 017, 986	24, 768	7, 454, 767	21, 252	6, 390, 641
Nebraska	127, 734	42, 024, 775	45, 493	12, 428, 669	42, 252	11, 732, 425
Kansas	165, 879	43, 729, 129	61, 698	12, 441, 985	53, 206	11, 028, 887
South Atlantic	1, 108, 061	88, 569, 458	549, 981	53, 870, 604	493, 093	48, 405, 196
Delaware	10, 257	899, 641	6, 319	451, 705	5, 752	408, 407
Maryland	49, 001	4, 433, 398	33, 771	2, 563, 394	28, 958	2, 191, 561
District of Columbia	139	3, 813	74	1, 141	48	719
Virginia	193, 723	17, 210, 174	130, 117	12, 262, 427	120, 186	11, 354, 497
West Virginia	90, 380	8, 979, 847	70, 203	6, 960, 333	59, 231	5, 943, 616
North Carolina	283, 482	18, 593, 670	132, 610	11, 254, 022	126, 944	10, 816, 955
South Carolina	172, 767	10, 638, 900	52, 401	5, 487, 499	42, 116	4, 381, 538
Georgia	249, 095	21, 945, 496	81, 108	11, 121, 240	73, 123	10, 047, 341
Florida	59, 217	5, 864, 519	43, 378	3, 768, 843	36, 735	3, 260, 562
East South Central	1, 006, 052	70, 606, 625	437, 141	44, 273, 446	375, 868	37, 910, 932
Kentucky	258, 524	19, 913, 104	155, 013	14, 323, 641	126, 517	11, 744, 108
Tennessee	252, 669	17, 901, 139	128, 305	11, 518, 843	121, 774	10, 958, 825
Alabama	237, 631	16, 739, 139	79, 282	8, 918 679	66, 508	7, 498, 513
Mississippi	257, 228	16, 053, 243	74, 541	9, 512, 283	61, 069	7, 709, 486
West South Central	1, 017, 305	165, 013, 316	346, 307	68, 784, 534	291, 600	58, 922, 760
Arkansas	221, 991	15, 632, 439	81, 540	8, 701, 647	70, 722	7, 652, 396
Louisiana	132, 450	8, 837, 502	47, 913	5, 128, 019	39, 009	4, 163, 802
Oklahoma	197, 218	30, 868, 965	60, 764	9, 289, 422	48, 174	7, 704, 416
Texas	465, 646	109, 674, 410	156, 090	45, 665, 446	133, 695	39, 402, 146
Mountain	233, 392	131, 689, 374	136, 803	40, 888, 381	111, 785	32, 831, 116
Montana	46, 904	32, 735, 723	23, 861	10, 165, 432	18, 638	8, 231, 156
Idaho	40, 592	8, 116, 147	24, 957	3, 792, 526	22, 629	3, 527, 268
Wyoming	15, 512	18, 663, 308	8, 342	4, 149, 798	6, 160	3, 047, 632
Colorado	58, 020	24, 167, 270	29, 292	8, 789, 276	26, 857	7, 785, 710
New Mexico	31, 687	27, 850, 325	21, 415	6, 938, 511	11, 842	4, 438, 911
Arizona	10, 802	11, 065, 291	6, 908	1, 986, 062	5, 574	1, 294, 887
Utah	25, 992	5, 000, 724	18, 777	3, 417, 517	17, 444	3, 087, 300
Nevada	3, 883	4, 090, 586	3, 251	1, 649, 259	2, 641	1, 418, 252
Pacific	265, 587	54, 258, 112	194, 166	22, 464, 768	164, 460	19, 703, 614
Washington	73, 267	12, 610, 310	53, 440	4, 729, 186	46, 706	4, 318, 805
Oregon	55, 911	14, 130, 847	39, 465	6, 590, 260	22, 194	4, 897, 784
California	136, 409	27, 516, 955	101, 261	11, 145, 322	95, 570	10, 487, 025
United States	6, 371, 640	924, 319, 352	3, 313, 490	419, 445, 827	2, 939, 960	370, 682, 381

Bureau of the Census, U. S. Department of Commerce.

For certain individual States, the size of the sample is not as satisfactory as for the country as a whole. But even there the data are sufficiently numerous to make them of far more significance than any other sample of such tax data known to have been obtained. Tax figures for the smallest percentage of owner-operated farms were reported from New Mexico, in which the percentage amounted to 55. Oregon was next, with reports from 56 per cent of the owner-operators.

It is to be expected that in those States in which the proportion of owner-operated farms is relatively low, the percentage of all farms included in these for which tax figures were reported to the census enumerators would be smaller than in the remainder of the country. In Mississippi, South Carolina, and Oklahoma for 24 per cent, or approximately one farm in four, tax figures were reported. From these States in which the percentages reached a minimum, they ranged up to their maximum in Maine and New Hampshire, where 91 per cent of all farmers reported taxes.

The description of the quantity of data gathered has been sufficient to indicate that it amounts in all States to a very extensive sample and that in some of them it is an almost complete enumeration. The remaining discussion of these data will consist of an analysis and comparison of the value and tax figures that have been assembled in the method and quantity that have been described.

The aggregate amounts of taxes and values of farm lands and buildings for each of the State and geographic divisions are reported in Table 33. The relationship of tax to value appears in the last column of this table.

TABLE 33.—*Taxes and value of owner-operated farms reporting taxes by States, 1924*

Geographic division and State	Taxes reported on farm land and buildings	Value of land and buildings of farms for which taxes were reported	Taxes per $100 of value
	1,000 dollars	*1,000 dollars*	*Dollars*
New England:	11,772	694,414	1.70
Maine	3,175	177,314	1.79
New Hampshire	1,559	75,185	2.07
Vermont	1,757	103,444	1.70
Massachusetts	3,496	195,656	1.79
Rhode Island	214	17,373	1.23
Connecticut	1,571	125,442	1.25
Middle Atlantic	28,003	1,794,203	1.56
New York	13,515	917,847	1.47
New Jersey	2,673	156,709	1.71
Pennsylvania	11,815	719,647	1.64
East North Central	73,971	5,078,174	1.46
Ohio	16,602	1,021,434	1.63
Indiana	13,858	698,354	1.98
Illinois	10,916	1,241,066	.88
Michigan	14,939	813,278	1.84
Wisconsin	17,656	1,304,042	1.35
West North Central	61,133	5,947,602	1.03
Minnesota	13,943	1,149,322	1.21
Iowa	17,487	1,833,025	.95
Missouri	6,915	883,890	.78
North Dakota	4,720	291,348	1.62
South Dakota	4,131	359,323	1.15
Nebraska	6,491	803,389	.81
Kansas	7,446	627,305	1.19

TABLE 33.—*Taxes and value of owner-operated farms reporting taxes by States, 1924*—Continued

Geographic division and State	Taxes reported on farm land and buildings	Value of land and buildings of farms for which taxes were reported	Taxes per $100 of value
	1,000 dollars	*1,000 dollars*	*Dollars*
South Atlantic	21,811	2,230,891	0.98
Delaware	273	27,028	1.01
Maryland	2,143	178,803	1.20
District of Columbia	16	1,177	1.36
Virginia	4,213	587,064	.72
West Virginia	2,782	230,452	1.21
North Carolina	5,635	496,061	1.14
South Carolina	1,767	179,666	.98
Georgia	3,000	250,882	1.20
Florida	1,982	279,758	.71
East South Central	14,863	1,227,206	1.21
Kentucky	4,950	452,570	1.09
Tennessee	5,033	449,228	1.12
Alabama	1,749	168,286	1.04
Mississippi	3,131	157,122	1.99
West South Central	17,623	1,667,607	1.06
Arkansas	2,550	213,348	1.20
Louisiana	2,065	133,572	1.55
Oklahoma	4,465	289,426	1.54
Texas	8,543	1,031,261	.83
Mountain	11,872	877,040	1.35
Montana	1,882	149,117	1.26
Idaho	2,680	184,093	1.46
Wyoming	497	50,354	.99
Colorado	3,296	225,879	1.46
New Mexico	600	51,071	1.17
Arizona	744	52,296	1.42
Utah	1,745	125,527	1.39
Nevada	428	38,703	1.11
Pacific	25,363	2,303,108	1.10
Washington	4,905	351,722	1.39
Oregon	2,574	207,459	1.24
California	17,884	1,743,927	1.03
United States	266,411	21,820,245	1.22

One caution needs to be kept in mind in any use that is made of this relationship. It is in no direct way connected with the legal tax rate which applied to the property. The legal tax rate is the percentage or the number of mills per dollar of assessed valuation that must be paid in taxes. The relationship here described is that which exists between taxes and the estimated true value of farm real estate. The preceding section of this bulletin indicated that no constant relationship exists between assessed valuation and true value. Hence, there is no constant relationship between the percentage that taxes are of true value and the tax rate based on assessed valuation.

A comparison by States of the relationship between taxes and values of farm lands in 1924 is made in Figure 15. The average tax paid was $1.22 per $100 of value. The variation among the States was from $0.71 per $100 in Florida to $2.07 in New Hampshire. There were 2 States in which taxes were less than $0.75 per $100; 7 in which they were between $0.75 and $0.99; 17 in which they were between $1 and $1.24; 10 including the District of Columbia in which they were between $1.25 and $1.49; 7 in which they were between $1.50

and $1.74; 5 in which they were between $1.75 and $1.99; and one in which they were over $2.

Such a comparison becomes more significant when it is directed toward the various sections of the country. In New England, the average taxes on farm land amounted to $1.70 per $100. Rhode Island, with $1.23, was the lowest, and New Hampshire, as has already been stated, the highest. Maine, Massachusetts, and Vermont, as well as New Hampshire, are among the 13 States in which the taxes are over $1.50 per $100. The average in the Middle Atlantic States is $1.56, and 2 of the 3 States, New Jersey and Pennsylvania, fall into the class in which taxes are over $1.50.

In the South Atlantic States, the average, $0.98, is the lowest for any section of the country. Three of the States, Virginia, South Carolina, and Florida, have average farm taxes amounting to less than $1 per $100 of value, and in none of them does the average amount to as much as $1.25.[21] Three of the four States in the East

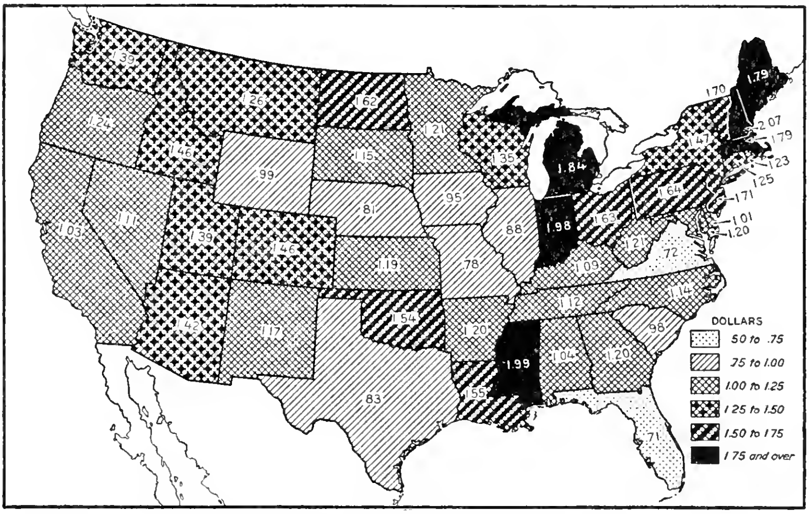

FIGURE 15.—FARM REAL ESTATE TAXES PER $100 OF VALUE OF OWNER-OPERATOR FARMS, 1924

Taxes in relation to value are highest in the Northeastern States and lowest in those of the Southeast. Farms in 6 States reported taxes amounting to over $1.75 per $100 of value whereas those in 2 reported taxes to be less than 75 cents per $100 of value.

South Central group report averages between $1 and $1.25. The fourth State, Mississippi, has an average of $1.99, which is the highest of any State in the South, and which brings the average for the group up to $1.21.

The figure for Mississippi is open to more question than any other that is quoted. On the basis of tax per acre it amounts to $0.41 and is higher than the per-acre figures for Alabama and Arkansas, which are $0.23 and $0.33, respectively, but not as high as that for Louisiana, which is $0.50.

The data have been examined for errors which might have arisen from two sources. In the case of those counties in which much land is rented, it was thought possible that owners had reported taxes on all their land, whereas value figures had been given for only the land

[21] The District of Columbia figure, applying to 48 farms, was $1.36.

they operated. There are 16 counties in the State in which the percentage of tenancy is over 80 per cent. The tax and value figures for these counties were computed, and taxes were found to amount to $1.99 on every $100 of value, just the State average. This result was compared with a similar computation for the 19 counties in which tenancy amounts to less than 40 per cent, and in these counties taxes amounted to $1.89 per $100 of value. The difference between these two results was not sufficient to indicate that the number of rented farms caused any large error in the results.

Special assessments were supposed to be excluded from the tax figures reported, but it was thought that the high rate of taxes in Mississippi might be explained by the reporting of levee and drainage district assessments as a part of the taxes on farm land. The plotting of the rate of taxation by counties on a map of Mississippi gives no indication that the high rate counties are concentrated in those sections of the State in which levee protection and drainage are needed.

The East North Central States show a wide variation in the rates of taxes based on values. They range from $0.88 per $100 in Illinois to $1.98 in Indiana and average $1.46. Michigan and Ohio, with rates of $1.84 and $1.63, respectively, are grouped with Indiana near the upper range of this section, and Wisconsin, with a rate of $1.35, is somewhat below its average. The seven States immediately west of this group have a lower average rate, $1.03. Three of them—Missouri, Nebraska, and Iowa—fall into the $0.75 to $0.99 group, three others are in the $1 to $1.25 group, and one, North Dakota, has a rate of above $1.50.

The West South Central States, with an average rate of $1.06, are heavily influenced by Texas, in which the rate is $0.83. The other three States of the group are well above this, Louisiana and Oklahoma having rates above $1.50.

The average in the Mountain States is $1.35, the rates of the individual States ranging from $0.99 in Wyoming to $1.46 in Idaho and Colorado. In the States on the Pacific coast, the average tax rate per $100 of estimated true value is $1.10. The California figure of $1.03 is of great weight in determining this average, the figures of the other two States being considerably higher.

These figures should be used with those which were discussed earlier in order to supply a fair idea of the weight of taxes on farm real estate. On the basis of income it was estimated that farm taxes took about 30 per cent of the net rent of farm real estate. Taxes in 1924 amounted to about 1⅕ per cent of the value of farm real estate; that is, for each $100 of taxes, there was produced by farm real estate $333 of net income on $8,333 of value. On the basis of these estimates farm land would yield a net income before taxes were deducted of 4 per cent. When taxes are subtracted, this becomes 2.8 per cent, which is only slightly lower than the 3.2 per cent estimated as the return to farm operators on their net capital investment in 1924–25.[22]

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[22] This estimate includes return to the operator as a business manager as well as return on net capital investment.

INCIDENCE AND EFFECTS OF FARM TAXES

The amount of taxes paid by farmers has now been estimated. The trend of such taxes over a period of years has been indicated. The relationships between taxes and various sorts of agricultural income have been discussed and compared with the relationships between taxes and income from urban land. The value of farm land has been compared with its assessed valuation and with the taxes that have been paid on it. All of this material is of value in an attempt to determine the tax contribution of agriculture.

An additional subject, as important as any of these, relates to the final payment of taxes. There is little burden to one who gives his money directly to the tax collector, if there is a process by which it is possible for the initial payer to add to his prices the amount of the taxes and so compel his customers to pay taxes for him. It is well now to examine briefly the possibilities, so far as agriculture is concerned, of shifting taxes from one group to another within the industry and, more important, of the chance that farmers have of making their customers outside of the industry pay the taxes which are levied on the farm. An attempt will be made to compare the farm-tax situation with that governing urban property and its taxes, and the shifting of taxes to farmers from other groups will be considered. The material relating to this form of shifting is not sufficient to make a quantitative study of the problem possible at the present time, but a description of the process by which such taxes are shifted will give some indication of its importance to farmers.

So far as the tax on farm land is concerned, there are two problems that need consideration. The first of these relates to the question of whether the owner or the tenant pays the taxes on rented land. This is of minor importance, when compared with the second problem—the possibility of shifting taxes from the farmer or the farm owner to other groups. Before either of these subjects is treated it is necessary to make a few generalizations relating to the possibility of shifting taxes.

A tax can be shifted only when some economic transaction is involved. The man who is taxed on a piece of property or on goods which he neither buys, sells, rents, nor uses in any process of making other goods for sale or rent, has little chance to shift the tax. In other words, unless we are able to add our taxes to the prices of the things we sell to others or subtract them from the costs of the things we buy, there is little chance for us to shift taxes. The study of the subject must be concerned then with a discussion of whether the taxes so affect supply and demand conditions as to make price changes possible. It should be understood that no change in price can occur unless the underlying demand and supply factors are affected.

Does the owner of a rented farm shift the taxes on that farm to his tenant? Does the taxation of farm land affect in any important way the supply of land to be rented or the demand on the part of prospective tenants for farms? Taxation can have little effect on the supply of land which is available for rental purposes. It may be that in rare cases a decision as to whether it will be desirable to operate or lease the land will be affected by the taxes levied on the land. Where this is true, the local supply may be restricted or increased, and the renter may be forced to pay more or may be enabled to pay less. If the first of these conditions exists, it may be possible for the landlord to shift for a short time a part of his taxes to the renter. It is extremely unlikely, however, that a situation will arise in which taxes will materially reduce the supply of land available for rental purposes. Other factors are far more important in determining whether land will be rented.

If taxes do enter into the determination, they are likely to force land onto the rental market rather than to keep it off. When a landowner's returns on land which he operates are reduced by taxes or other factors, the first tendency is for him to attempt to increase the yield of that land by operating it more intensively. If he is not successful in adding to the yield to the extent that he thinks necessary, he may try an alternative method of securing income from his land by renting it. Thus, taxes may be a factor in causing more land to be rented. The effect of taxes on the supply of land available for renting is probably insufficient to cause an important amount of tax shifting.

Will taxes increase the demand for rented land, and by this means make it possible for the landowner to shift a part or all of his taxes? Contract rent which the tenant is willing to pay will be determined in the first instance by competition among those who wish to rent land in a particular section and, over a short period, may have little relationship to the economic rent of the land. Over a period of several years (and this, rather than a single year, should be the chief concern of one who attempts to determine the effects of a policy of taxation), economic rent will form the maximum that can be paid for land. It is possible that the expenditure of money raised by taxation will increase the economic rent of a piece of land. If the proceeds of the taxes are used, for example, to build a road by which easy and rapid access to markets is secured, then the economic yield of the land will be increased just as much as if it had been possible to add increased fertility. Although the establishment of good schools is a less tangible feature than is the creation of better marketing facilities, it, too, will add to the desirability of the land and will in course of time influence the rents which tenants are willing to pay for land.

For these reasons it is believed that there is a possibility that a part of the taxes on land may be shifted to tenants. Whether this possible increase in the rent is sufficient to counteract the decreases in rent which may come through increased supply of land placed in the rental market by the pressure of taxation, by the development of transportation, or by other means, is perhaps doubtful. Both factors are at work, and both should be considered. The lack of any correlation between benefit and taxes in the case of individual farms should also be considered as a factor which is likely to prevent shifting from owner to tenant.

The shifting of taxes from owner to renter in the case of city property is more likely to occur than in the case of farm land. Improvements form a far more important part of the city property. The fact that taxes may influence the improvement of city property needs no explanation. When taxes on real estate are at such a rate that building is retarded, the available supply of buildings may prove inadequate, and the rent received for them will be increased, thus causing a part or all of the tax to be shifted to the tenant. On the other hand, a policy of partial or total tax exemption of improvements or other encouragement of overbuilding will have the effect of making the tax fall wholly on the landlord.

In the cities, the influence of the things for which taxes are spent in making property more productive are far more important than they are in the country. They may make certain properties more desirable from the tenant's point of view. Thus, the demand price for such properties will increase, and there will be a tendency toward shifting a part of the taxes to the tenant.

Under certain circumstances in both city and country, shifting from the landlord to the tenant takes place, but as it is far more likely to occur in the case of city property, so far as farm property is concerned, this aspect of the problem needs little attention. The more important question concerns the possibility of shifting the tax to the consumer who purchases the product of farm and city property.

The answer, so far as farm property is concerned, is fairly simple. Farm taxes may be passed on to the consumer only if they increase the price which the farmer receives for his products. Although taxes on farm products will influence the market demand for such products through their effect on prices, the immediate effect of taxes will come through increasing or restricting the supply of the products. When taxation causes land in general to be used more intensively, the result will be an increase in the supply and so will tend to decrease price. Thus, it is impossible for farmers in general to add to the unit price of their product a sufficient amount to enable them to pass the tax on to the consumer.

Whether the increased production caused by the taxation will result in a greater return to farmers is a problem which can not be solved without an extended investigation of the effect of increased supply on demand. The lowering of the price of some products is sufficient to bring many new buyers into the market with the result that the price decline is soon stopped. On other products a lowered price will stimulate few new purchasers, and an increased supply will cause a marked decline in price. Many agricultural products are in this latter class.

From this brief analysis, it seems safe to conclude that not only are farmers in general unable to add their taxes to the unit prices of their products, but the increased production which taxation may cause rarely results in an increase of the farmer's net return.

An additional point needs mention. The effect of an increase in taxation on an individual farmer may be different from that on farmers as a group. The increase may make an individual utilize his land more efficiently than previously. In other words, the heavier financial burden will force the individual to use new means of adding to his income from the farm. If he is successful in doing this, the tax may not prove a burden to him, even though he is not able to shift it. Such an effect of increased taxation is possible only where land has not been developed to its highest productive capacity, and it will benefit only occasional individuals.

One special set of conditions under which farm taxes can be shifted to the consumer needs brief mention. If the product of farms has a local market and if the product can not be brought in from other producing sections, an increase in taxes sufficient to cause the abandonment of some of the farms may cause the supply of the product to be so reduced as to increase its price. Thus it would be possible for the farmers who are able to remain in business in the section to shift a part or the whole of their taxes to the consumer. The conditions under which this would be possible are such that with present-day competitive sections and methods of transportation the situation could hardly arise. The further fact that the taxes might cause an increase in production on the farms which remained in operation would tend to make the shifting less possible. In a case of this sort a part of the taxes are not shifted, since abandonment of the land will involve the drying up of the source of a part of the revenue, and thus the governmental unit will be deprived of the amount that had previously been collected from the abandoned land.

It has already been shown that the general property tax on town and city real estate is often shifted from the landlords to the tenants, and in the case of business property there is the possibility of passing the tax on to the consumer of the products of the business. Two cases will be considered, that which arises if the production and sale of the products is local, competing only with other enterprises subject to the same taxing jurisdiction, and that which exists if the products are sold in a wider market. These are important to the farmer since he spends a large proportion of his income in the purchasing of goods which pass through the hands of town and city manufacturers and dealers.

In neither case will taxation affect the immediate demand for the products. Its effects on the supply side will determine whether the tax can be shifted. In the first case, all businesses within the city will be compelled to pay the tax. Those enterprises which would be barely able to exist if they were not taxed will have to increase their prices or go out of existence. If they increase prices, other firms, better situated, will be able to undersell them and in the end the weaker ones will be driven out of business. The supply of goods available will be reduced, and those who remain in business will, through the increase in the price of that which is left on the market, be able to shift a part of their taxes to consumers.

It is possible that the increased production and sales of the surviving firms may lower their unit costs of production and that through competition the price to the consumer will be lowered. Differing supply and demand conditions may tend to overcome the normal tax-shifting process. In spite of these conditions which may bring about exceptions to any general rule, it seems correct to state that if production and market are local the tax generally is shifted to the consumer.

In the second case, the market is assumed to be more than local. Tax conditions will differ between one producing unit and another. If it be assumed that aside from taxes the units are subject to essentially equal conditions, it will be possible to shift to consumers only an amount of taxes equivalent to that paid by the unit which is taxed least, or, stated in another way, to shift the taxes that are common to all of the units. Hence, under some conditions only a small portion of the taxes may be shifted.

From this involved consideration of the most intricate problem connected with public finance, a few conclusions that may be drawn are the following:

(1) Taxes on rented farm property may be shifted from landlord to tenant only under certain unusual conditions.

(2) The shifting of farm taxes to the consumer will occur only under conditions that are so rare that few farmers at the present time are able to make consumers pay their tax bills.

(3) Taxes on rented city properties tend to be shifted by the owners to their tenants when the property is located in a section of a city in which the supply of buildings has dropped behind the demand.

(4) Taxes on business properties in towns and cities tend to be shifted to the consumers of the goods or services supplied by the business to the extent that (*a*) the production and market are local, or (*b*) that the market is general and taxes are generally applied to competing firms by a large taxing unit or by several units with similar types of taxes of substantially equal amounts.

(5) Such taxes on business properties tend to be shifted to farmers to the extent that farmers are consumers of these goods and services.

These conclusions, and the others which might be reached if it were possible to examine the incidence of the general property tax on various types of property which have not been considered, are stated in order to illustrate the extreme difficulty of measuring the tax burden. They do not depict all the difficulties involved in the process. Even if the incidence of taxes could be measured accurately and a definite expression in percentage of income paid in taxes secured, the problem would not be solved. Certain intangible benefits are received from taxes which have thus far defied numerical expression. Then, too, ability to pay taxes helps to determine tax burden, and ability to pay is in part a function of income. Ten per cent of an income of $1,000 is a far greater burden than 10 per cent of an income of $100,000. The type of income also helps to determine tax-paying ability. Income derived from investments should be able to bear higher taxes than income derived from personal earnings.

The difficulties in measuring the burden of taxation are not so great that no conclusions can be drawn from the data that have been presented. It has been estimated that taxation—Federal, State, and local—takes from 10 to 12 per cent of the current income of the country. It was found that the owners of rented farms were paying around 30 per cent of their income from this kind of property in State and local taxes. It is possible that other State taxes were paid out of this same income, and if it formed part of an income above the exemption limits, a tax on it was paid to the Federal Government. No shifting process took place which passed this tax on to the consumer, so it was paid either by landlord or by tenant—almost always by the former.

Farm real estate, then (and to a considerable extent city real estate could be included) is subject to a far higher relative tax payment than is the average type of income-producing property. An analysis of our methods of financing State and local governmental expenditures would suggest that this must be true. The figures that have been discussed earlier in this bulletin confirm the accuracy of the suggestion. This fact needs consideration in any attempt to readjust tax payments. There is probably only a small group of the country's population which believes that real estate should be subject to a tax burden much greater than that applied to other types of property. The majority feels that measures tending to reduce this inequality deserve consideration.

READJUSTMENT OF FARM TAXATION

SUMMARY OF INVESTIGATIONS OF FARM TAXATION

Students of American tax problems have long been familiar with the fact that tangible property, particularly real estate, has been made to pay most of the expenses of State and local government. As these expenses have increased, the pressure of taxation on real estate has gradually become greater until there has arisen from many sources the demand that the burden of taxation on this type of property be made less heavy. Summarizing briefly the major points of this bulletin, it is possible to indicate their relationships to the wider field of Government finance and to point out tentatively the direction that alleviation of the present difficult situation may take.

That farm taxes are high is no new discovery. The particular value of the quantitative analyses here given lies in the presentation in a single bulletin of scattered data, some of which are published here for the first time. These data tend to confirm the belief, which students of the subject have expressed in recent years, that farm real estate is bearing an extremely heavy weight of taxation. They also tend to corroborate each other in that they point toward the same general conclusions.

Farm taxes in 1927 were estimated to be over $900,000,000. Most of this amount was paid through the general property tax and through taxes levied on automobiles. Trends in farm taxation for the country as a whole and for certain individual States indicate that from 1914 through 1917 the rise in taxes was gradual, that from 1918 to 1923 there was a drastic increase, and that since 1923 there has been a small increase each year.

An attempt was made on the basis of intensive studies in 14 States to compare taxes with the earnings of agricultural property. This resulted in an estimate that taxes, at present, are taking about 30 per cent of the net rent of farm real estate. An examination of the results of studies of the return on farm property and on the owners' managerial abilities indicated that on farms operated by their owners taxes had, in the past six years, amounted to from 18½ to 31 per cent of such returns.

Average figures do little to indicate actual conditions. At many points throughout the study an effort has been made to indicate the importance of variations from the average. Inequalities in assessments do much to cause the variations between farms in the percentage of return taken by taxes. The conclusions and certain of the data of a few studies of the relationship of assessed valuation of farm lands to their true value illustrate some of the types of inequality and show their effect on the distribution of the tax levy. Improvement in the assessment process was shown to be one of the prime requisites of any program of tax reform.

In the relationship comparison between taxes and the estimated value of farm property, the data examined showed wide variations from section to section of the country and undoubtedly would have shown great difference between one and another farm if the study could have been carried down to the individual properties concerned. In 1924 taxes were reported to have taken on the average 1⅙ per cent of the value of the farm real estate of the country. The slight increase in farm taxation since that year and the decline in the value of farm real estate had, by 1927, probably increased this to 1⅓ per cent of the value of farm property.

It has been made clear that farm property is heavily taxed and that, along with other real estate and certain other classes of tangible property, it is bearing more than its reasonable share of the cost of local government. The methods by which the local units are financed places on tangible property almost the whole weight of local expenditures.

This bulletin is not designed to present an ideal solution for the tax difficulties of the various States. No single program could be satisfactory to all of the 48 States. Local considerations and differences in economic and fiscal structures must play their parts in determining the directions that tax reform must take. A few suggestions will be made, but in each case they must be qualified by the understanding that local conditions may make them entirely unsuited to the tax situation of certain of the States.

The tax structure needs to be considered as a whole. It must be recognized that Federal taxes exist along with State and local taxes and that it may be unfair for a State to attempt to increase materially the taxes of a type of business which is already bearing a heavy tax burden. An example of this situation is found in the case of certain corporations. Their State and local taxes are relatively low, but when the Federal corporation tax is added to the contribution to State and local governmental units, the proportion of net income taken by taxes becomes fairly high. In the case of manufacturing corporations for 1926, for example, State and local taxes took only 11.6 per cent of net income, whereas all taxes amounted to 23.8 per cent (*18, p. 315–316*).

This need for considering all aspects of the situation is emphasized as a means of calling attention to the limitations that must be placed upon conclusions based on the results of this and of other studies. The importance of the questions of the incidence and the effects of taxes on any type of property or of business must be given close consideration before any general program of tax reform can be adopted.

POSSIBILITIES OF FISCAL REFORM

The following suggestions of tax revision are made, then, subject to the qualifications that have been discussed. It is believed that they are worthy of consideration in the majority of the States in which farm taxes constitute a heavy burden. They concern four general types of change:

(1) Improvement of the administration of taxes in use at the present time.

(2) Addition of new types of taxes to the present tax system.

(3) Broadening of the base of support of the various governmental activities.

(4) Reduction of expenditures through administrative economy and the elimination of duplications of governmental functions.

IMPROVEMENT OF TAX ADMINISTRATION

Improvement in the administration of local farm taxes must be centered around the problem of assessment, because it has been found that faulty assessment is the cause of much of the inequality of taxes among farmers. In no section of the country in which the subject has been investigated have the assessment methods been of a type that would bring satisfactory results. But varying degrees of inequality have been found under different conditions, and it seems possible to suggest certain general methods which will improve assessments in those jurisdictions where they can be used.

There are some who urge that the basis of assessment—sales value—is a faulty one and that no marked improvement can be expected until it is replaced by other criteria of value. The possibility of substituting income for capital value as a basis for assessment has been discussed.[23] A few States, by direct mention or by implication, include income as one of the factors to be used in computing the assessed valuation of real estate. In every case, present and prospective incomes are factors that influence sales values, although in some cases the incomes are far in the future and are expected to be derived from uses other than the ones to which the property is put at the present time. Over a short period speculation in land may become so chaotic that land will be bought and sold with only the slightest thought of possible returns after the speculative period is over. Entire reliance on current income as a method of determining assessed valuations would not be feasible at present because methods of measuring current income from real estate have not been developed to the point where they can be used by assessors. It must also be recognized that assessed valuation based on the actual—rather than the potential—income of farm land might tend to place a premium on the inefficient utilization of land. In any event, a tax system which used an assessed valuation based on current income would have to include a tax on increments in land value, as these would often not be reflected in income for a long time after the value had risen.

In view of the difficulties in connection with the use of income from real estate as the basis of its assessed valuation and in view of the fact that there is no immediate chance of many States changing their assessment basis from sales value to current income, discussion of improvements in the methods of assessment will be concerned with assessed valuations made on the basis in use at present. All of the improvements suggested, however, will be equally necessary in any revised system. Changes in administration, in personnel, and in methodology are given brief attention.

In many States the assessing districts are too small to provide full-time work for trained employees. So many different assessors are concerned that a single standard of work among them is practically impossible. Each assessor is to a considerable extent independent of others, and although his work is subject to review there is no administrative body that is in direct charge to outline methods and check results. Remedies that have been used in a number of States to meet this situation provide first for an assessing district large enough to employ the full time of a trained man. In most rural sections a county assessor will be more satisfactory than a township assessor,[24] and it is possible that in many places it might be desirable for two counties to agree to employ one assessor to do the work in both jurisdictions.

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[23] Compare the discussion of the subject in Mass. Agr. Expt. Sta. Bul. 235 (*21, p. 92–93*) and Ark. Agr. Expt. Sta. Bul. 223 (*1, p. 22–28*).

[24] The situation, so far as township assessors are concerned, is well described by R. Wayne Newton and W. O. Hedrick (*14, p. 57–58*).

Increased supervision of assessment methods and results by State authorities will aid in establishing uniformity. Many States at present provide valuable assistance to the local assessing officials. Certain of the means used will be referred to in the discussion of personnel and of methodology. Others relate to the direct power of checking the accuracy of a local assessor's work and of ordering and, if necessary, of carrying on a reassessment where the work is not satisfactory. At present 15 States give to State supervisory officials, usually to the State tax commission, the power to make reassessments on their own motion and with their own agents. Ten other States give their supervisory officials the power to order reassessments. Such powers, although necessary, are rarely used.

A State supervising body can do most to improve assessments by carrying on research activities that are impossible and would be uneconomical in the local assessment districts, by acting as a court of appeal for individual and group assessments, and by adjusting or equalizing assessments among the various taxing jurisdictions. Studies of the results of past assessments by comparing sales and assessed valuations, and of methods by which equality of assessment may be attained are among the useful activities to be carried on by the State commissions. The results of such research can be utilized by the local assessors to reduce the inequalities of farm taxation.

It is difficult to generalize on the subject of personnel connected with the present assessment systems. No one doubts the necessity of trained men. Assessment calls for highly specialized ability. The need of training and ability has been satisfied in different parts of the country by various methods. It seems to be generally agreed by students of the subject that the assessor's office should be appointive rather than elective. But it is necessary to do more than to fill the position by appointment, if the work is to be improved. Some assurance that men appointed have the necessary qualifications must be provided. A possible solution is to permit only the appointment of men certified by the State tax commission as eligible for the office. Certification would be dependent on satisfying rather stringent requirements to be made by the commission.

To attract trained men to the position, it will be necessary to make appointments for a period of at least five years. A man becomes more valuable in the position as his experience in it increases. The salary must be sufficient to make men with the required education and ability look forward to the assessor's position as affording a satisfactory living while giving public service.

Improvements in the method of carrying on the work of assessment relate partly to instruction and supervision which may be provided by State supervising bodies, such as tax commissions. They should be empowered to demand uniformity in the reports made of the various factors that enter into the determination of assessed valuation. Land classification, for example, should be uniformly handled in various sections of the State. The values given to each type of livestock should not vary between one assessor's jurisdiction and another's. Types of equipment, such as maps and rating cards, should be similar for all sections. Assessment rolls should be made up and indexed on a uniform basis. Reports of changes in the ownership of property should be secured on a systematic and uniform basis.

Several of these methods of improving assessments are in wide use among the States. Most of them are in use in at least a few sections of the country. Half of the States are on a county-assessment basis. Nearly one-third of them give to State supervising officials the power to order and to carry out a reassessment of property. Assessors are appointed in only six States and in these the appointments are usually on a political rather than a merit basis.

In no State except parts of Delaware and Rhode Island does the term of office of the assessors exceed four years. Office procedure, maps, card indexes, and other efficient instruments for carrying on effective assessment vary from county to county within all States. There is likely to be more uniformity in those States in which there is direct supervision of the assessors, or in which assessors' meetings are held under the auspices of the State.

Massachusetts is an example of a State which exercises direct supervision over the records and methods of its assessors. Colorado holds meetings of its assessors, and members of its tax commission are required to visit the several counties at stated intervals. Most State tax commissions or boards of equalization make attempts to compare assessed valuations with true or sales value. This involves collecting a certain amount of information concerning the sale of real estate in various sections of the States. Some of the commissions do a thorough and excellent piece of work. Wisconsin has been an outstanding example of efficiency in this respect.

In no State in which information is available from studies similar to those described in this bulletin has the limit of improvements that are possible (with the present system of supporting local government largely by taxing tangible property) been approached. There is no evidence that the condition is greatly different in the other States. Although it is believed that the system itself needs extensive alteration, since tangible property will occupy the most important place in the local tax systems for many years to come, it is essential that all possible means be used to bring greater equality into the assessment of farm and other property. So doing would give distinct relief to much property that is overburdened. It would not reduce the amount to be collected by taxation of general property, but it would distribute that amount on a fairer basis.

NEW TYPES OF TAXES

State and local taxation at present are based on the general property tax, but all States are using the taxation of automobiles and a tax on gasoline to supplement the tax on general property. A certain amount of revenue, large in a few States, is derived from the charters, fees, and other taxation of corporations. About one-quarter of the States tax the incomes of individuals. Inheritance taxes, poll taxes, excise taxes, and a few special varieties such as severance and franchise taxes, contribute a small proportion of the total taxes collected. In 1922, the general property tax accounted for 83 per cent of the total State and local tax collections of the country.[25] In 13 States the percentage ran above 90. At the present time, the percentages are somewhat smaller because of the increase in taxes on motor vehicles and on gasoline, but the contribution of general property is still estimated as well over 75 per cent of all taxes collected.

[25] Special assessments were not classed as taxes in computing these figures.

In 1922, three-quarters of the property reached by the general property tax was in the form of real estate. There has probably been little change since that date. If the general property tax supplies 75 per cent of the total State and local tax collections, then real estate is contributing between 55 and 60 per cent of such collections. Few would maintain that real estate's share of total earnings, or its relative ability to pay taxes, constitutes such a large percentage of total income or of aggregate tax-paying ability.

Aside from intangible property, much of which entirely escapes direct taxation, there are many sources of tax-paying ability which are neglected by the tax programs of the majority of the States. It is urged that each State reconsider its taxing system in order to determine whether it is distributing its taxes over as wide a base as possible. It is probable that every State is neglecting certain sources of revenue which should be tapped in order to make each of the various groups in the State pay its fair share of the cost of governmental services.

From the standpoint of the farmers, any equitable tax which diminishes the contribution of real estate will be of assistance. All States use certain taxes to supplement the tax on general property. By the use of classified property taxes owners of intangibles have been made to contribute more than they did in the past to the support of the Government. Increased use of the income tax and of certain excise taxes on nonessentials has been found advantageous in some States. In certain jurisdictations in which the exploitation of consumable natural resources makes a severance tax possible, such a tax has provided additional tax income.

BROADENING OF THE BASE OF SUPPORT OF CERTAIN GOVERNMENTAL ACTIVITIES

In some States the use of new taxes can provide only slight relief to agriculture. A county that is dependent on agriculture for its revenues will benefit only slightly if its contribution to the cost of State government is reduced or eliminated. So long as poor counties are dependent on their own citizens and property for the financing of most of the governmental services provided, there can be little reduction of farm taxes.

This fact is receiving wide recognition. Road systems supported by the States are expanding in most sections of the country. Most people will agree that a highway which is used mainly by through traffic should be constructed and maintained by the groups that are benefited by it rather than by the local communities through which the road may pass. Use of the gasoline tax and the automobile license tax is modifying the incidence of road costs. The tendency toward State and nation-wide support of through highways has probably not gone as far as it should, but the need of such support is being given attention in all sections of the country.

The interest of the farmer in the expansion of the State highway systems needs little explanation. Every expenditure that can be removed from the local governmental unit and distributed over the wider unit in the proportion that the wider unit enjoys benefits from the expenditure and has the ability to contribute toward such expenditure, should be so assigned. The result will be a more equitable tax situation. Much needs to be done to determine whether individual roads are local, district, State, or nation-wide in their use and benefits. Many roads now considered to be only the concern of individual townships are doubtless of as much importance to the residents of the adjacent or even distant towns or cities as they are to the farmers whom they serve directly.

In the case of education, the responsibilities of wider units are being recognized. County-wide school taxes serve to distribute the cost of education more evenly among the districts. State aid, based on the needs of individual districts, tends to give the children in the poorer districts greater educational opportunities than they could have if the district or county were left to pay the expense without assistance. It is proper that such grants should be made by the larger units since the benefits of education are by no means confined to the district in which a child may happen to receive his training and since the ability to pay for education is unevenly divided among various sections of the State.

Payment of educational costs by means of funds collected from the larger units will assist agriculture since most of the poor districts are rural. Farm boys or girls are usually the ones who attend the school in a district that is unable to provide educational facilities equal to the standard now demanded by parents for their children. The majority of the districts that must tax themselves heavily in order to maintain schools to conform to the minimum standards set by the States, are rural districts. The use of the taxable property of the State as a whole, or even of a wider base, will make possible educational improvements and will relieve many farming sections of their high tax contributions to maintain schools.

Emphasis is placed on the need of financing roads and schools by means of tax contributions from the larger governmental units, but it is not implied that these are the only functions which should be financed on a wider basis than is common at the present time. They do, however, comprise so large a proportion of the total governmental costs of the rural sections of the country that relief here will do much to render farm taxation less burdensome.

REDUCTION OF EXPENDITURES

Reduction of governmental expenditures at a time when people are demanding additional services is difficult. No one questions the desirability of all possible economies, as long as essential services are not curtailed. Difficulty arises in attempts to agree on economies that are possible and on services that are not essential. Any attempt to point out specific lines of economy in a general study of this sort would be of little value. Each spending jurisdiction has its own problems which need intensive study before any conclusions concerning the curtailment of costs can be reached.

Attention is called to the tendency toward the reorganization and consolidation of governmental functions which will give more efficiency and will lessen essential expenditures. The reorganization of departments in several of the State governments has made possible better service without increasing costs. Consolidation of the work of assessment within counties and possibly among counties has already been mentioned. Tax collection could be carried on much more efficiently in many jurisdictions (*9*). School districts are often too small to be economical or to give their pupils the advantages that can be furnished in districts in which schools can be organized in grades.

Reconsideration is needed in all rural sections of the country of the functions of certain governmental units. In many cases two or more counties could be consolidated. In some cases two complete sets of county officials are doing the work which might as well be done by one group. In the days when travel was slow and communication difficult, counties of the size of those in most of the agricultural States were needed. This need has largely vanished. The governmental services of most of the States would be improved by the reduction of the number of counties by at least one-third.

The county is not the only governmental unit that needs reappraisal to establish its worth. It is mentioned as perhaps the most striking example of this need, but in many sections of the country much the same criticism might be made of the smaller units, such as townships or school districts.

Recognition must be given to the fact that the elimination of the vested interests of any group of governmental officials is difficult and that county officers in some sections of the country are most strongly intrenched in office. Communities will be reluctant to give up the prestige that comes through being the county seat. The attitude in this case should be the same as is assumed toward other luxuries. If the people concerned can afford them and want them, no one would maintain that they should be deprived of them. But where the maintenance of unnecessary county or other units creates an impossible tax burden or makes impossible the maintenance of adequate governmental services such as schools, public-health service, or roads, then every effort should be made to eliminate the unnecessary units.

It may be that in some sections of the country there are no units that could be eliminated. The data to support a statement that such elimination is possible or desirable in all sections of the country have not been assembled. On the basis of a limited experience with such consolidations, it is believed that they furnish one means of economy that will render governmental service more efficient. Direct plans for such action must be based on local conditions. A detailed investigation of the functions and the efficiency of the local units of government would be a necessary preliminary to such action.

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PRINCIPLES OF BOX AND CRATE CONSTRUCTION

BY

C. A. PLASKETT

Senior Engineer, Forest Products Laboratory
Forest Service

United States Department of Agriculture, Washington, D. C.

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TECHNICAL BULLETIN No. 171 — APRIL, 1930

UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

PRINCIPLES OF BOX AND CRATE CONSTRUCTION[1]

By C. A. PLASKETT, *Senior Engineer, Forest Products Laboratory,*[2] *Branch of Research, Forest Service*

CONTENTS

FOREWORD

The container industry is very closely associated with industrial expansion, and the cost, weight, and efficiency of the container is often a large factor in the profitable market range of a commodity.

The forester and the timber owner are interested in containers because they are mostly manufactured from forest products and can

[1] See p. 2 for footnotes 1 and 2.

be manufactured from mill waste and low-grade lumber, thus tending toward more efficient utilization of our forests. The ultimate consumer is vitally interested because efficient containers help to make available to him commodities from distant points and because the cost of the container, as well as loss and damage claims and unnecessary freight, are in the long run borne by him. Originally regarded as a side issue, container development lagged behind our general industrial and transportation expansions, but with wider distribution of commodities, with the demand for lighter and cheaper containers, and with the demand for better protection of the commodity, came the necessity for a fundamental study of the container. The Forest Products Laboratory has been making such a study for many years and has published various articles and reports in which the interpretation of the results has been limited to a specific problem.

This bulletin brings together the various principles involved in efficient box and crate construction and shows their interrelation. The application of the principles developed and recommended in this bulletin should aid in stabilizing the container industry, in reducing loss and damage, in making cheaper and more efficient containers, and in making possible the continued profitable use of great quantities of low-grade and waste material produced in the manufacture of lumber.

J. A. NEWLIN,
In Charge of Timber Mechanics, Forest Products Laboratory.

INTRODUCTION

Our present consumption of forest products, because of its magnitude and urgency, can not be met or maintained by timber growing alone. It must be supplemented by vastly improved utilization. Through improved utilization, all the merchantable timber we now have, whether in virgin forests or second growth, must be made to go as far as it will. Since over 13 per cent of all the lumber cut annually goes into lumber for boxes and crates and in addition 7 per cent of the wood pulp produced annually is used for the manufacture of fiber containers, it is clear that a thorough understanding of the fundamental principles of box and crate construction will be reflected in the more efficient utilization of the wood of our forests.

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[1] This bulletin embodies the results of shipping-container investigations by the Forest Service that have extended over more than 20 years. It has been the author's privilege to draw without restraint upon the vast accumulation of information that has resulted from studies on shipping containers and allied subjects by various members of the Forest Products Laboratory staff. Other sources of information have also been freely drawn upon. The author particularly wishes to make acknowledgment to J. A. Newlin, who from the beginning has guided the container investigations of the Forest Products Laboratory, and under whose direction the work has progressed to its present status. In addition acknowledgment is made to the following members of the laboratory staff: T. R. C. Wilson, for assistance in the presentation and for critical review of the manuscript; J. M. Gahagan, for data on the holding power of nails and for other assistance; I. B. Lanphier, for many of the investigations on nailed wooden boxes, wire-bound boxes and crates, and plywood boxes; T. A. Carlson, for much of the data on corrugated and fiber boxes and for the design and development of the score-testing machine used in testing fiber containers, as well as for data on the suitability of various woods for boxes and on the effect of moisture content of wood on the strength of boxes; G. E. Heck, R. F. Luxford, and I. B. Lanphier, for those data in the bulletin relating to the use of knotty lumber in box construction; and to L. J. Markwardt, for the information in Table 7 on the comparative strength properties of container woods together with the description thereof. Specialized information on container woods, their production, and their preparation for use has been derived from Forest Products Laboratory investigations by Eloise Gerry, Arthur Koehler, G. M. Hunt, Rolf Thelen, and C. V. Sweet. Acknowledgment is made to D. L. Quinn, formerly of the Forest Products Laboratory, who from his broad experience in the application of the principles of container construction has given the author many valuable suggestions. It is a pleasure to acknowledge also the cordial and valuable assistance, so indispensable to the furtherance of the principles of box and crate construction, received from representatives of users and manufacturers of shipping containers and container materials and from members of transportation organization. The abundance of assistance so received makes impractical separate acknowledgments.

[2] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

The chief object of this bulletin is to present the principles of efficient box and crate construction which are based on extensive investigations and experiments at the Forest Products Laboratory, supplemented by study and observation of shipping containers in service. The leading conclusions have been confirmed by manufacturers and shippers after critical review and tests under actual service conditions.

The application of these principles to all types of containers for all classes of commodities is not discussed in detail; yet sufficient examples are included to show their practical significance and how they may be applied to specific problems. An effort is made to show that there are well-established principles of efficient box and crate design and that the correction of the troubles experienced with containers in service should be based on reasoning from principles. Particular attention is given to the kinds of failures to which each type of container is subject, and to the changes in construction that will overcome these failures or render their recurrence less likely. Broad distinctions among various classes of commodities and conditions of service are discussed.

Since the hazards that any container may encounter in service are so numerous and variable, no endeavor is made to set up standards of service or to designate the types of containers that are most suitable for specific commodities or conditions of service. To do so would be like designing a bridge without a knowledge of the loads to be carried.

Packing is as important as the design of the container, and the two are so interrelated that it is impossible properly to design the container without considering the method of packing. A brief discussion of the principles of internal packing, together with some examples of their application, is included. The appendices present information on the characteristics of the principal woods available for box and crate construction, the seasoning of lumber, container testing, formulas for the design of boxes, and standard specifications for boxes of various kinds.

HISTORICAL

Until the building of railroads and the resultant increase in trade the use of shipping containers was comparatively small. The wooden box was the first type of modern shipping container to be manufactured. Lumber was then so plentiful and cheap that box manufacturers, like nearly all other users of wood, demanded high grades and ignored inferior material. Waste in the woods and at the mills and box factories received scant consideration. Little attention was given to designing boxes so as to obtain the maximum strength for the minimum of materials. The constant lessening of forest area and the ever-increasing demand for lumber, however, raised the cost of the higher lumber grades and forced the box maker to use the lower and cheaper grades. More attention was given to using less lumber for the different box parts, and where formerly only a few kinds of wood were used for boxes, many kinds were brought into use. To-day several billions of feet of lumber are used annually by box manufacturers, and, for the most part, this material is of such low grade that if it were not consumed for this purpose it would be left as waste in the woods or at the mill.

Fiber boxes were comparatively unknown as shipping containers until the present century. They were first introduced as cartons, a number of which were packed and shipped in a larger wooden box. The constantly increasing demand for lighter and cheaper containers soon caused competition between fiber and wooden boxes. In 1906 the fiber box had found a small use as a shipping container and was accepted by the western railroads with restrictions. Three years later three railway-classification committees accepted the fiber box interchangeably with the wooden shipping container for the smaller sizes and for weights of contents up to 90 pounds.

To meet the competition of the lighter and cheaper fiber box, and to reduce loss and damage and shipping costs, the wooden-box industry turned its attention to reducing the weight and cost of its product, to better proportioning the parts of the boxes and to various ways of reinforcement. Several new types of boxes, such as the wire-bound, cleated plywood, and hinge-corner boxes, were also developed.

The first recorded laboratory tests (*8*)[3] for the improvement of shipping containers were made in 1905 by the Forest Service in cooperation with Purdue University, at Lafayette, Ind. The purpose of these tests was to determine the merits of different kinds of wood as box material. The method of test consisted of applying a load along the diagonal of a box to simulate the action which occurs when a box is dropped on one of its corners. These early investigations clearly demonstrated that the details of construction have far greater influence on the strength of a box than the species of wood used and indicated the need for extensive studies of the design of shipping containers.

After the establishment of the Forest Products Laboratory at Madison, Wis., in 1910, research on container design was greatly expanded and centered at this laboratory, where special testing machines and methods of testing have been developed. The chief endeavor of the laboratory in connection with shipping containers has been to develop the fundamental principles of design and the relationships of the various details necessary to produce containers that are balanced in strength. Other container-testing laboratories, patterned after that of the Forest Products Laboratory, have been established by box manufacturers, by associations of manufacturers, by shippers, and by box specialists. The chief function of these laboratories is to apply the fundamental principles and to adjust the various details of design to the needs of the individual shipper.

To further the movement for improvement in containers, the carriers, and manufacturers of containers and of container materials, together with other interested agencies, have organized to develop better practices. The efforts of these various interests have led to the recognition of the United States as the foremost country in the development of shipping containers.

RELATION OF TRANSPORTATION CONDITIONS TO CONTAINERS

In recent years the demand for the quick delivery of goods has resulted in longer and heavier trains, faster operations in distributing cars and making up trains, and more expeditious handling of packages at receiving, transfer, and delivery points. New equipment and new methods of handling are continually being introduced to speed

[3] Italic numbers in parentheses refer to "Literature Cited," p. 132.

operations and to reduce costs. Such developments do not necessarily result in increased hazards to the commodities shipped; on the contrary, the hazards in many instances are reduced.

While with this development of transportation and handling methods has come remarkable progress toward the uniformity of the shocks incident to shipping, yet there is a wide variation in the intensities of the shocks that packages encounter under any particular combination of transportation and handling methods. Packages of miscellaneous commodities shipped in a car encounter shocks and stresses that are severer and of a greater variety than are encountered by packages of a carload lot of a single commodity. Furthermore, the shocks and stresses encountered differ between localities. Severely congested and less congested districts demand different facilities and methods of transportation; likewise different equipment and methods of handling are required at different water terminals. Shocks to containers in motor-truck shipment are less severe than in railway shipment; yet the severity of the weaving and wrenching strains may be greater in the motor truck.

The hazards in export shipment are more numerous, more variable, and usually more severe than in domestic shipment; an export shipment may meet all the hazards of domestic transportation before being loaded into the vessel and after reaching a foreign port may undergo the further hazards of a long journey inland. The hazards from the tendency of cargo to shift in rough seas as well as those from varying climatic conditions are, as a rule, more severe than the hazards in domestic shipment. Furthermore, goods must frequently be unloaded from vessels into lighters, and if the sea is rough this occasions extremely severe handling.

A commodity in shipment may need protection against numerous other kinds of hazards. For instance, great losses sometimes occur from theft in transit; therefore certain products require containers that can not be readily opened and reclosed without detection. Again protection against vermin or severe weather is often important.

RELATION OF THE COMMODITY TO CONTAINER DESIGN

The purpose of any shipping container is to aid the commodity to withstand the hazards of transportation and to facilitate handling and stowage. The nature of the commodity, therefore, is a fundamental consideration in designing a container.

The protection needed varies from the mere holding together of a number of such units as railway spikes to elaborate protection of delicate X-ray tubes. Some articles have highly polished surfaces, some have slender legs or other projecting and fragile parts, and some have large thin plates of easily broken material. Other articles have heavy parts supported by relatively weak parts, such as the heavy rim of a flywheel with slender spokes, and still others, such as acids and explosives, are a menace to life and property.

It is evident, therefore, that each commodity presents its own problem, and consequently neither weight, nor distance traveled, nor method of shipment taken alone constitutes an accurate criterion for designing a container. Even with the innumerable kinds of damage and hazards, however, relatively few kinds of stresses and fundamental principles of design are involved.

The following are the forces and stresses produced by shipping hazards: Crushing, bending, shearing, diagonal distorting, twisting, puncturing, and abrading. The principles involved in aiding the commodity to withstand any one of these stresses are the same regardless of the hazard that produces the stress, and frequently the same principle may be employed to prevent several different kinds of stresses. For instance, diagonal distorting, or twisting, may result in racking of the joints in a piece of furniture, rubbing of the finished surface against the container, breaking of thin plates of glass, or chipping of enamel ware. One of two principles may be employed in preventing these stresses and the consequent damage: (1) The container can be made rigid so that it can not distort diagonally in any direction, or (2) the container can be made nonrigid and the product so packed that the container can distort considerably without touching or without introducing stresses in its contents. The relation between the damage observed and the methods of overcoming any particular trouble are discussed under the different types of containers.

ECONOMIC FACTORS ENTERING CONTAINER DESIGN

The best container for a given service is one which will deliver the commodity satisfactorily at the minimum of total cost. Its design is subject to all the varying conditions of cost, value of the commodity, protection required, method of packing, transportation hazards, freight charges, personal and property damage likely to result from handling or from failures, inconveniences of making replacements, and facilities for handling and transporting packages.

A balanced container is one in which each part has strength in balance with that of every other part. Such a container, however, may not be the most economical because it may be made of high-grade expensive wood rather than of a low-grade inexpensive wood which would give equal service; it may require a multiplicity of sizes of material rather than a relatively few standard sizes or may be otherwise expensive to manufacture or to pack; it may not have sufficient strength to deliver its contents in a satisfactory condition, or it may contain more material and have greater strength than is necessary. Furthermore, the balancing of the construction depends upon the hazards to which the package is subjected and a container whose construction is so balanced that under one set of shipping conditions one kind of failure is just as likely to occur as another may under other conditions be subject to but a single kind of failure.

Containers and packing which deliver every unit in every package undamaged may be quite inconsistent with minimum total cost, since the ideal container will always be so light and fragile that occasional accidental rough usage will sometimes cause a small amount of damage. It should be borne in mind, however, that the economic loss resulting from delay, loss of good will, and the cost of making settlements is always greater than indicated by claims filed against the carriers. In addition, it must be recognized that all losses are reflected in the ultimate cost of the commodity to the consumers.

IMPORTANCE OF LABORATORY TESTS IN CONTAINER DESIGN

Consideration of the nature of the commodity and the economic factors involved leads to the conclusion that there can be no fixed standards of serviceability or fixed rules of design for containers. Some general principles and rules have been worked out experimentally and may be used to advantage in designing an original container or in correcting difficulties experienced in service, but it is impossible to make definite rules for designing boxes and crates which will have just sufficient strength to deliver the commodity without damage.

Tests and experiments that reproduce in the laboratory the stresses of transportation are of utmost value in determining the principles to apply in designing containers, in developing rules for the detailed application of these principles, and in showing how containers may be lightened and reduced in cost; yet such tests do not furnish a measure of the minimum resistance needed. Because of the lack of definite information on the requirements of service, it is seldom possible to find the best design of container and packing for a given commodity other than by making successive improvements as dictated by diagnosis of failures or damage occurring in service. Study of failures and damages experienced in service will usually reveal the nature of the stress and suggest the principles to apply. In some instances the cause of damage will be apparent, but in others neither the container nor packing may show evidence of failure, yet the character of the damage to the commodity may reveal that the stress resulted from such causes as the sides of the container springing in, diagonal distortion, twisting of the container, or the use of too rigid packing materials.

COOPERATION REQUIRED TO PRODUCE SATISFACTORY CONTAINER

The proper adjustment of all factors involved in designing containers requires the combined organized effort and close cooperation of laboratories, manufacturers, shippers, carriers, and consumers. The design of containers having the minimum required strength is complex, but to attain the most economical distribution of the commodity is still more intricate. Such distribution must be studied not only on the basis of designing the most economical containers for existing conditions but also on the basis of reducing the hazards of transportation and the cost of handling, of designing the commodity to better withstand shipment, and of eliminating unnecessary and expensive trade customs. It is evident, therefore, that what constitutes the most economical container will vary with improvements in container design and in methods of packing, with variations in transportation and handling methods, and with changes in economic conditions. Although the ideal container can never be attained, careful study will usually result in improving containers, lessening their cost, reducing transportation hazards, lowering costs of handling, and reducing loss and damage.

APPLICATION OF PRINCIPLES

Examples of the practical application of the fundamental principles of efficient box and crate construction contained in this bulletin are given in the specifications presented in Appendix G. Although primarily intended for the use of Government purchasing units, the specifications may be employed by the manufacturer, the jobber, and the dealer. These specifications give detailed information on the construction of various sizes, kinds, and styles of boxes for different classes of commodities.

The principal purposes of the discussion given on pages 9 to 39, inclusive, are to afford the reader information that will be helpful in selecting the best type of container for a specific service and more particularly to show him how study of failures in containers in service may be made the basis of improving the container.

Although the formulas, rules, and specifications presented in Appendixes E and G are the best available guide to the design of container of any of these types for a specific service, it is seldom possible to determine the best design of container other than by making successive improvements to correct weaknesses developed in service. The following discussion of principles will serve as a guide in the making of such improvements.

DESIGN AND CONSTRUCTION OF BOXES AND CRATES

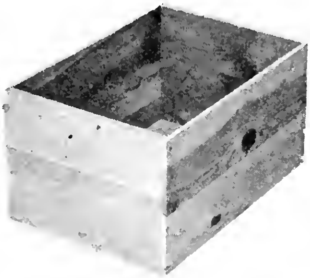
TYPES OF CONTAINERS

To satisfy the varying conditions of service, a number of well-defined types of containers, such as nailed wooden boxes, crates, fiber boxes, barrels, baskets, drums, plywood boxes, and wire-bound boxes, have been developed. Each of these, because of the very nature of its design and the materials of its construction, fulfills some particular purpose better than the others. In selecting a type of container for a specific use it should be remembered that what constitutes a weakness in a container for one commodity may be an advantage for another commodity. The characteristic strength and weakness of several types of boxes and crates and the construction details influencing their serviceability are discussed in the following pages.

INFLUENCE OF SIZE AND FORM OF WOODEN MEMBERS ON THEIR STRENGTH AND STIFFNESS

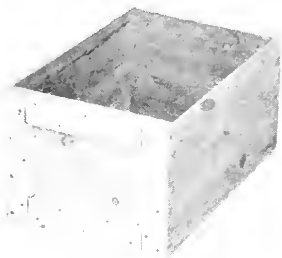
In designing any wooden box or crate a knowledge of the relation of the form and size of each part to its strength is necessary. The static bending strength of a box part varies inversely as its length, directly as its width, and directly as the square of its thickness. For example, a box side 20 inches long will support twice as much static load as one 40 inches long; a side 8 inches wide will support twice as much load as one 4 inches wide; and a side 1 inch thick will support four times as much load as one one-half inch thick, the other dimensions and the quality of the lumber being the same in each case. The stiffness of a part varies inversely as the cube of the length, directly as the width, and directly as the cube of the thickness. The ability of a part to withstand shocks or blows without breaking varies directly as its length, its width, and its thickness; that is, the shock-resisting capacity of a box side increases in the same ratio as each of its dimensions. Resistance to splitting at the nails or to nails shearing from the end of the piece increases with its thickness and with the distance of the nails from the end of the piece.

Torsional rigidity of individual members varies inversely as their length, directly as the cube of their thickness, and approximately,

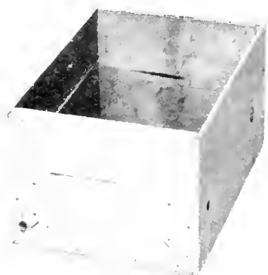


STYLE 1

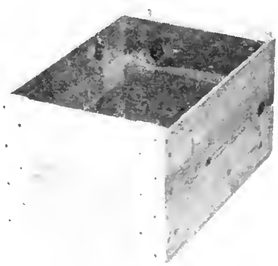
STYLE 2



STYLE 2½

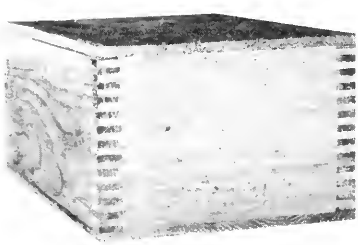


STYLE 3



STYLE 4

STYLE 5



STYLE 6

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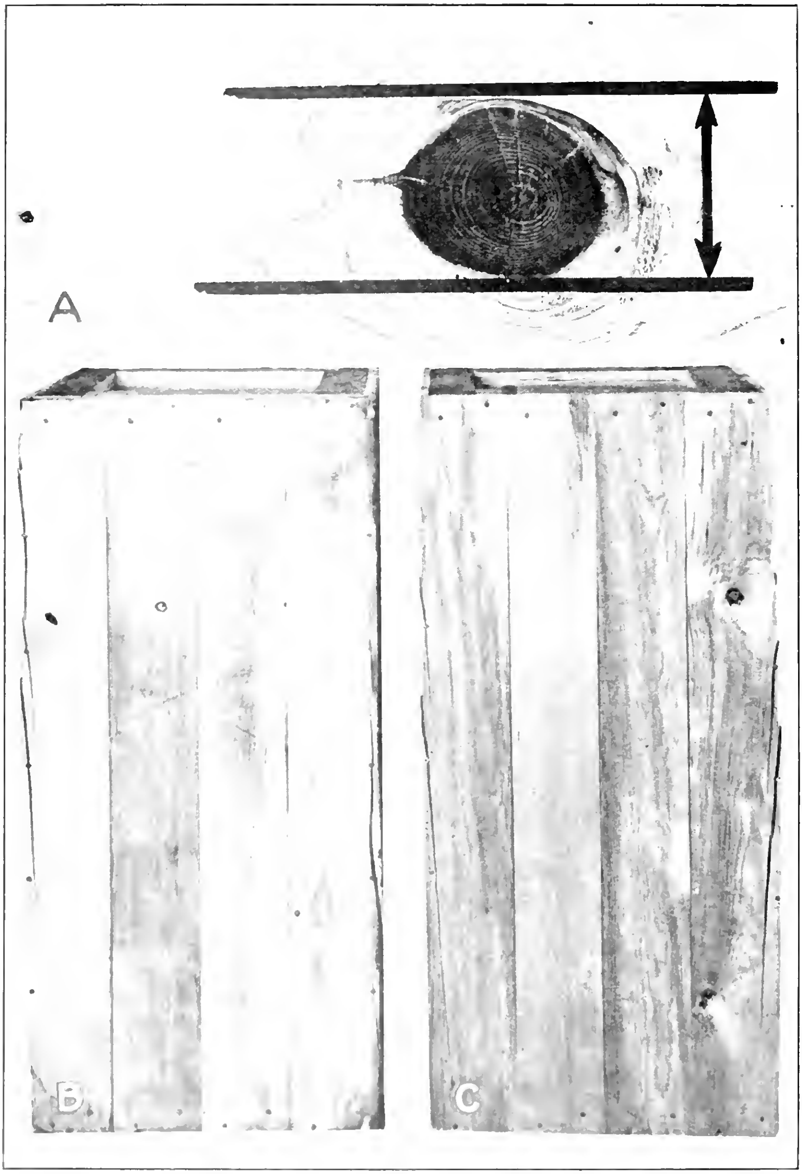
STANDARD STYLES OF NAILED WOODEN BOXES



M9755F

A, Method of measuring knots; B and C, typical failures of side nailing directly as their width. Torsional stresses are seldom considered in container design but are sometimes the cause of failure.

All of the foregoing relationships apply to plywood when they are properly modified for direction of grain and for the number and thickness of plies. (See p. 22.) Their application to fiber board requires a knowledge of the properties of the individual plies. (See p. 31.)

NAILED AND LOCKED-CORNER BOXES

The several styles of nailed and locked-corner wooden boxes shown in Plate 1 have been developed to meet the requirements of different commodities and conditions of service, and have been adopted by the National Association of Wooden Box Manufacturers. The end construction is the basis of the classification.

The outstanding characteristics common to all these styles are great resistance to crushing, puncturing, and mashing of the corners. They stack well, are easy to manufacture, and the strength of each may be readily adjusted to different service requirements by varying the details of construction.

DETAILS OF CONSTRUCTION

Thickness of Sides, Top, and Bottom

Although the joints and fastenings are actually the principal points of weakness in boxes, it is common belief that the thinness of material for sides, top, or bottom is limited by the breaking strength of the lumber. As a matter of fact the thicknesses of these parts are usually determined by nailing requirements rather than by the breaking strength of the lumber. Because the resistance of wood to withdrawal of nails, to splitting at nails, and to shearing at nails is low in comparison with its other strength properties, it is impractical with clear material to so proportion box ends and the fastenings at the joints that failure will be by breaking across the grain of the sides, top, or bottom.

The type of nail failure depends on the relation of the thicknesses of sides, top, and bottom to the size of the box. Repeated bending of long thin sides, tops, and bottoms causes the nails to work loose, to shear out, or to split the part that holds their points. In boxes with relatively short and thick sides, the shocks incident to rough handling are not absorbed by the springing of the boards, and failures occur as a result of the contents of the box pulling directly on the nails. If boxes are properly nailed the two types of failure are about equally common when the slenderness ratio, that is, the ratio of length to thickness of the boards in the sides, top, or bottom, is about 60 to 1. Failures by the repeated bending of the box boards become more prevalent as the slenderness ratio increases, and failures by direct pull increase as this ratio decreases. In boxes with wide faces consisting of a number of narrow boards, the weaving of the box in service loosens the nails and produces the same type of failures as occur in boxes with long sides of thin material.

For the same thickness of end, boxes with wide sides permit better nailing than boxes with narrow sides and therefore require less thickness of material for the same gross weight in order to prevent nail failures. Box sides made of wide boards, especially single-piece sides, resist weaving of the box and loosening of the nails and require less thickness to resist the nails shearing out at the ends of the boards than box sides having two or more pieces in the sides. Failures occur in such boxes, however, through the thrust of the contents knocking out the ends or through the direct pull of the contents on the nails.

Knots or knot holes slightly reduce the stiffness of the board in which they occur and reduce the breaking strength almost in the ratio of the width of the knot to the width of the board. By using boards containing knots or knot holes the breaking strength of the boards in a box part may be brought into balance with the strength of the nailed joints. With the sides, top, or bottom boards having a slenderness ratio of less than 60 to 1 in boxes where the knots or attendant cross grain does not prevent proper nailing, there is no reduction in strength for a knot or knot hole whose diameter (measured as indicated in pl. 2, A) does not exceed one-third the width of the board, or from knots or knot holes whose aggregate diameter within a length equal to the width of the board does not exceed the diameter of the largest knot allowable. But in boxes with long sides of thin material, the size of the knots must be further limited in order to avoid the sides breaking across the grain, or to avoid loosening of the nails with the increased bending of the boards. The increased bending resulting from knots, however, may be readily offset by a very slight increase in thickness of sides.

Boxes for heavy commodities require better nailing and thicker material than those for light commodities. Lightweight commodities, however, often require relatively thick material in the box sides, tops, and bottoms in order to prevent damage to the commodity from the springing or puncturing of the boards. Since lightweight packages frequently receive severer handling than heavier packages, thicker lumber and better nailing in comparison to the weight of contents are required. If springing, puncturing, and breaking across the grain as well as nail failures are to be avoided, the thicknesses of the box sides, top, and bottom should be varied with the weight and nature of the contents and with the size of the box. The thicknesses required for the sides, top, and bottom of a box may be approximated by the formulas given in Appendix E. Less thickness is required for the dense hardwood species having high-strength properties than for lightweight species having low-strength properties.

Thickness of End and Size and Shape of Cleats

The requirements for the thickness of box ends and the cross-sectional area of cleats are affected by many factors, a number of which counterbalance each other and thus make their consideration unnecessary in designing a box. For practical purposes the dimensions of the box ends and of the cleats are determined by the style of the box and by the thickness of the sides, which in turn is dictated by the nailing requirements. Uncleated ends require greater thickness in proportion to the thicknesses of the sides, top, and bottom than cleated ends of boxes for the same service. Ends or cleats that receive part, or all, of the nails that are driven through the box sides, top, and bottom, must resist both breaking across the grain and splitting at the nails and consequently must be thicker, and the cleats must also be of greater cross-sectional area, than when they receive only part or none of the nails. These facts are illustrated by the style 5 box (pl. 1), in which the ends receive all the nails and in the style 2 box, in which the cleats receive a part or all of the nails. Cleats that do not receive the points of nails should not be excessively thin; otherwise they will fail to give stiffness to the box end, and they will break readily.

Varying the shape of the cleats is often an advantage in box construction. Triangular cleats in the box corners give greater rigidity to the box than rectangular cleats of the same cross-sectional area. Square cleats afford greater rigidity and greater resistance to splitting at the nails and to breaking by static loads than other shapes of rectangular cleats of the same cross-sectional area, but are less desirable where the cleats are placed outside of the box since the required length of sides and the displacement of the box are then increased.

Unless the cleats are defective, failure by breaking across the grain indicates that they are too thin or too small in cross-sectional area. Splitting of box ends or splitting of the cleats at the nails, provided the nailing is not at fault, indicates that the lumber is too thin.

Since box ends seldom fail by breaking across the grain, larger knots may be permitted in the ends than in the sides, tops, and bottoms. Provided they do not interfere with the nailing, knots, knot holes, or clusters of knots whose diameters, measured as illustrated in Plate 2, A, do not exceed one-half the width of the board in which they occur do not reduce the strength of the box. Only very small knots, however, should be permitted in the cleats.

Size and Spacing of Nails

Box parts may be of sufficient size to permit adequate nailing and to resist breaking across the grain, and yet failures at the joints may occur as the result of improper nailing. The nails may be of the wrong kind, size, or number, or they may be improperly spaced or carelessly driven.

If the nails are short and comparatively thick the weaving of the box and the bending of the box sides, top, and bottom will cause the nails to work back and forth to their full depth in the wood, thereby reducing the resistance to withdrawal, or the prying action will split the piece holding the nail points. On the other hand, if the nails are slender and are driven to a considerable depth the weaving of the box and the bending of the box parts in service will bend and break the nails between the parts that are joined. Splitting of the box ends and cleats at the nails may usually be overcome by using longer nails of smaller diameter. On the other hand, failures by the nails breaking between the parts united may be overcome by increasing the diameter and decreasing the length of the nails. Some bending of the nails is an advantage because it prevents them from working loose and absorbs some of the shocks that tend to cause the nails to shear out. Furthermore, resistance to shearing the nails out at the ends of sides, tops, and bottoms is increased slightly by the heads cutting into the wood. Shear failures may be overcome by increasing the number of the nails, which permits decreasing their size without causing other types of failures. If the nails pull out, either the number of nails or their length should be increased. If the heads pull through the wood, a larger number of nails or nails with larger heads in proportion to their length should be used. Figure 1 presents the results obtained in drum tests to show the relative amount of rough handling required to cause loss of contents in nailed boxes fastened with a different number of nails. A box with seven nails per nailing edge is taken as the basis for comparison. Cement-coated nails (p. 49) normally offer greater resistance to withdrawal than barbed or uncoated smooth nails, but are of little advantage in preventing the nails from shearing out at the ends of the boards or the heads from pulling through.

Splitting of the sides, top, and bottom may occur in driving the nails if the nails are too large in diameter. Splitting of ends or cleats in nailing sides, tops, and bottoms to them may occur if the nails are too large in diameter or too long or if too many are placed in a row. Staggering of nails, as well as reducing their size and number, aids in overcoming such splitting.

"Side nailing," or nailing through the top and bottom into the edges of the sides, adds little to the strength of the box, since the weight of the contained commodity and the hazards encountered in service spring the box sides and produce splitting of the top and bottom at the side nails. (Pl. 2, B and C.) Even in strapped boxes the springing of the box sides is often sufficient to cause side nails to

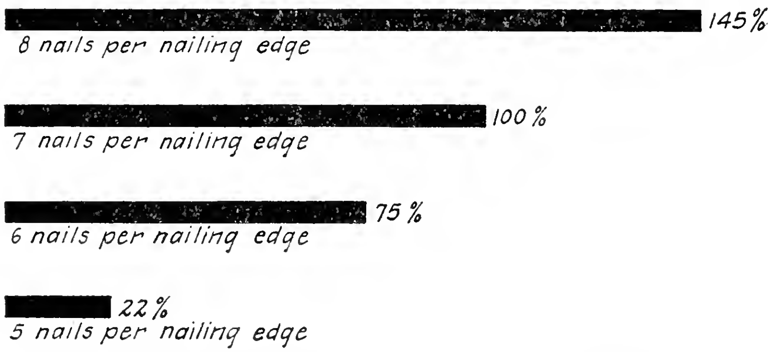


FIGURE 1.—Relation of number of nails to amount of rough handling required to cause loss of contents. Boxes for 2 dozen No. 3 cans nailed with sixpenny nails

split the box top and bottom. After such splitting, side nails are a danger to hands and clothing.

If the nails pierce two pieces and are clinched one-eighth to one-fourth inch at right angles to their shanks, fewer nails are required. The character of the shank of a clinched nail is relatively unimportant since the resistance to withdrawal depends upon the clinched end.

As previously indicated, the nailing required for a box varies with the thicknesses of the box sides, top, and bottom, and with the number of boards in each part. However, the maximum size of the nails that may be used satisfactorily is usually limited by the kind and thicknesses of the wood in the ends and in the cleats. If the sides, top, and bottom are of comparatively thin material, care should be taken not to overdrive the nails. Overdriving a nail (p. 51) crushes the wood fibers surrounding the nail and reduces the resistance to the nail head pulling through the wood and to the nail shank shearing out at the end of the piece.

Proper nailing is obtained when no one type of nail failure predominates and there is as much likelihood of one type of failure as of another.

Moisture Content of Lumber

Manufacturers and shippers often make boxes out of lumber that has not been properly seasoned. Although this lumber is termed "dry" it may contain 25 per cent or more moisture. The use of green or wet lumber of this kind is very poor practice because a box made of such lumber quickly loses most of its strength (*3*) and becomes decidedly inferior to one made of dry lumber. Shrinkage of the green lumber in drying loosens the nails so much that the weaving action during transportation often causes them to work out. Furthermore, the nails driven into the side grain of the box ends and

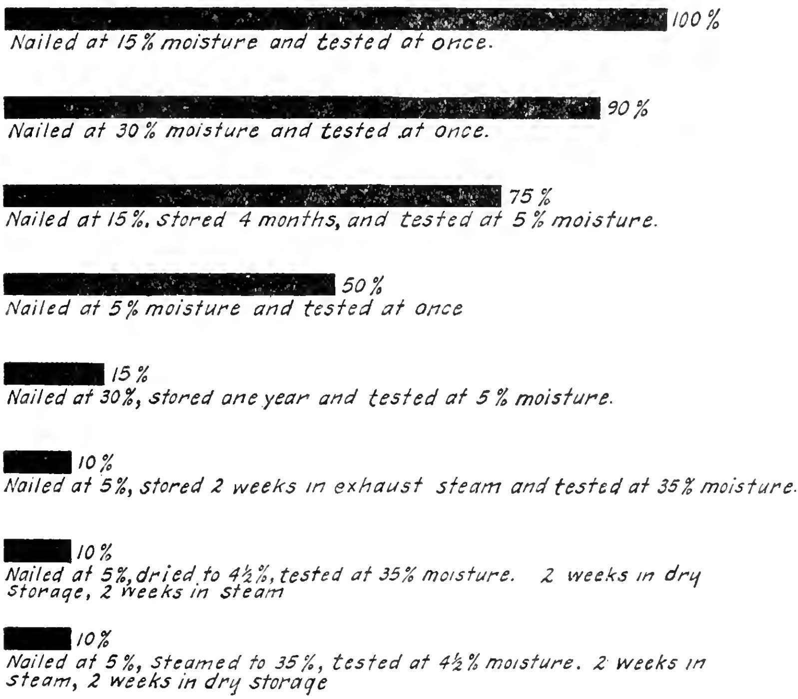


Figure 2.—Effect of moisture condition at time of nailing and change in condition due to storage, on strength of boxes, the basis of comparison being boxes nailed at 15 per cent moisture content and tested at once. Boxes are for 2 dozen No. 3 cans, nailed with seven cement-coated nails to each nailing edge. Average results of tests of boxes made from a single species of wood

cleats resist the shrinkage of the side, top, and bottom boards and cause the boards to split.

The weakening effect caused by the drying of the wood after the boxes have been nailed is indicated in Figures 2 and 3. It may be noted that boxes made of green lumber and subsequently dried in storage lose at least 75 per cent of their resistance to handling. Under such conditions the cement coating on the nails loses its effectiveness in preventing withdrawal. Barbed nails (p. 49) have greater holding power than either uncoated or cement-coated smooth nails after the wood into which they are driven has dried. It may be noted, however, that before the drying of the wood the barbed nails have less holding power than any of the other types.

The use of very dry lumber in boxes is objectionable because the driving of the nails breaks down the wood fibers more, and dry lumber splits more readily both in nailing and in service than lumber having a higher moisture content. A box made of lumber containing 12 to 18 per cent moisture will withstand ordinary storage conditions without a great loss in serviceability. However, even when boxes are to be made of lumber that has the proper moisture content, they should not be assembled with cement-coated nails until needed, since in time cement-coated nails lose part of their resistance to withdrawal even with no change in the moisture content of the wood into which they are driven (p. 52.)

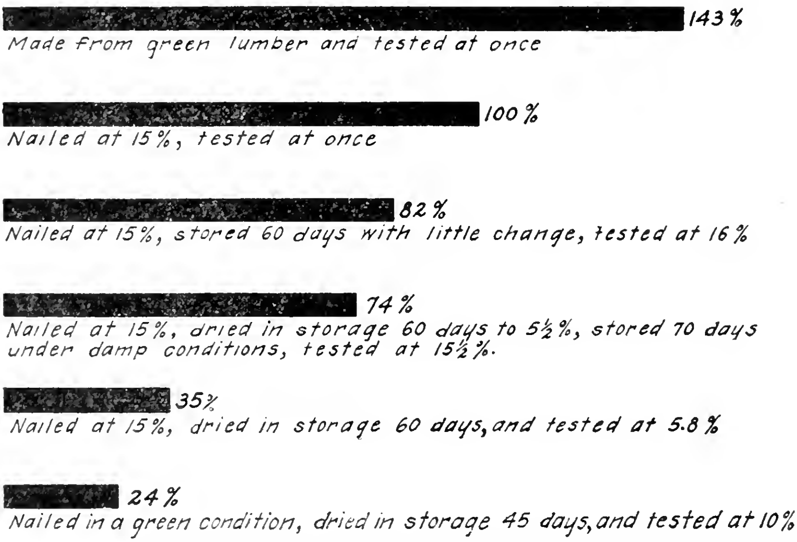


FIGURE 3.—Effect of the drying of lumber after nailing, as shown by the resistance of boxes to rough handling. The boxes nailed at 15 per cent moisture and tested at once are taken as a base. The boxes were for 2 dozen No. 3 cans, nailed with seven cement-coated nails to each nailing edge. These results are the average of tests on boxes made from seven species of wood

NUMBER OF PIECES

The number of pieces in the various parts of a box greatly influences its strength. Boxes with several narrow boards in the sides, top, and bottom have less resistance to diagonal distortion and weaving than those with a smaller number of wider boards; consequently more bending stress is transmitted to the ends and cleats. In such boxes the weaving action loosens the nails, splits the pieces holding the nail points, shears the nails out at the ends of the boards, or breaks the nails off between the two pieces united. Boxes with parts consisting of a number of boards therefore require better nailing and thicker lumber than boxes with parts made of a single piece. Wide stock also has the advantage over narrow stock in that larger knots may be permitted. Furthermore, the use of wide stock makes pilfering from the box more difficult. Narrow boards are least objectionable in cleated box ends.

Edge Joints

The weakening effect of two or more boards in a box part may be overcome by securely joining the edges of the boards together. The Linderman joint (pl. 3, C) is the most satisfactory joint for boxes. It is most effective when tapered lengthwise, to produce a wedging action, and properly glued.

Great care is necessary to make a strong glue connection whether in plain butt, tongue-and-groove, or ship-lap joint. (Pl. 3.) The strength of a part built up in this manner depends entirely on the efficiency of the glued joint. Unless reinforced by other fastenings, glue in butt, tongue-and-groove, or ship-lap joints can not ordinarily be depended upon for strength since such joints are usually inaccurately fitted and poorly glued.

Corrugated metal fasteners (pl. 3, B) are also used for joining the edges of box parts. For best results corrugated fasteners should be driven alternately from the opposite faces of a box board. Common practice is to use corrugated fasteners in the ends of uncleated boxes: they are seldom used on the side, top, or bottom joints of a box, although they produce very good joints for this purpose. When glued joints are drawn together with corrugated fasteners immediately after spreading the glue the pieces are held together during the setting of the glue, and much stronger glued joints result.

All of the foregoing types of joints are less effective in material less than one-half inch in thickness than in thicker material.

Rotary-cut Lumber and Plywood

One of the principal advantages of rotary-cut lumber and plywood for box construction is that these materials are produced in widths sufficiently great to permit almost any box part to be made of a single piece. Rotary-cut lumber for box construction is relatively thin, usually one-fourth inch or less in thickness, and has practically the same strength properties as sawed lumber of the same species of wood, grade, and thickness. Rotary-cut lumber is comparatively free from defects since it is usually produced only from relatively smooth logs. Consequently, the rotary-cut lumber used for boxes is usually of better quality than the sawed lumber. Like sawed lumber, its chief weakness is comparatively low resistance to splitting and to shearing along the grain. Plywood (p. 68) has a strength more nearly equal in all directions than rotary-cut or sawed lumber and has the additional advantage that it may be built up to any desired width or thickness. Plywood has much higher resistance to splitting, either at the nails or otherwise; to shearing out at the nails; and to puncturing, than has sawed lumber. It is extensively used for panel boxes, but is seldom used in the common styles of nailed wooden boxes, although it is well adapted for such boxes.

Direction of Grain

It is common practice in box construction to make the ends the small faces of the box and to place the boards of the end, sides, top, and bottom with their grain lengthwise of the face although in very large boxes the boards are sometimes placed with their grain running the short dimension of the box face. Boards placed with their grain running the short dimension of the box make a weaker box than boards with their grain running lengthwise of the box. Such boxes require a greater number of boards, and since the boards are short they have less capacity to spring and thus relieve the direct pull of the contents on the nails.

Styles of Boxes

Style 1 (uncleated end) and style 6 (locked-corner and dovetail) (pl. 1) are neat and attractive constructions, but are suitable only for small boxes carrying relatively light loads, usually not over 60 to 100 pounds. The size of box and the weight of contents for which these styles may be used depends on whether the box has 1-piece sides and on whether the commodity is able to support the box against its characteristic weakness, which is its tendency to split entirely around parallel to the top and bottom. Such splitting is likely to occur if the box drops on its corners or edges or if its sides or ends are subjected to a puncturing action. When a box having joints in the sides drops on any of its corners or edges, the upper section of the box has a tendency to slide past the lower section. If this action is not prevented by the commodity itself it is resisted only by the strength of the box end in bending across the grain. The most effective method of strengthening an uncleated box (style 1 or 6) against such failures is the use of 1-piece sides.

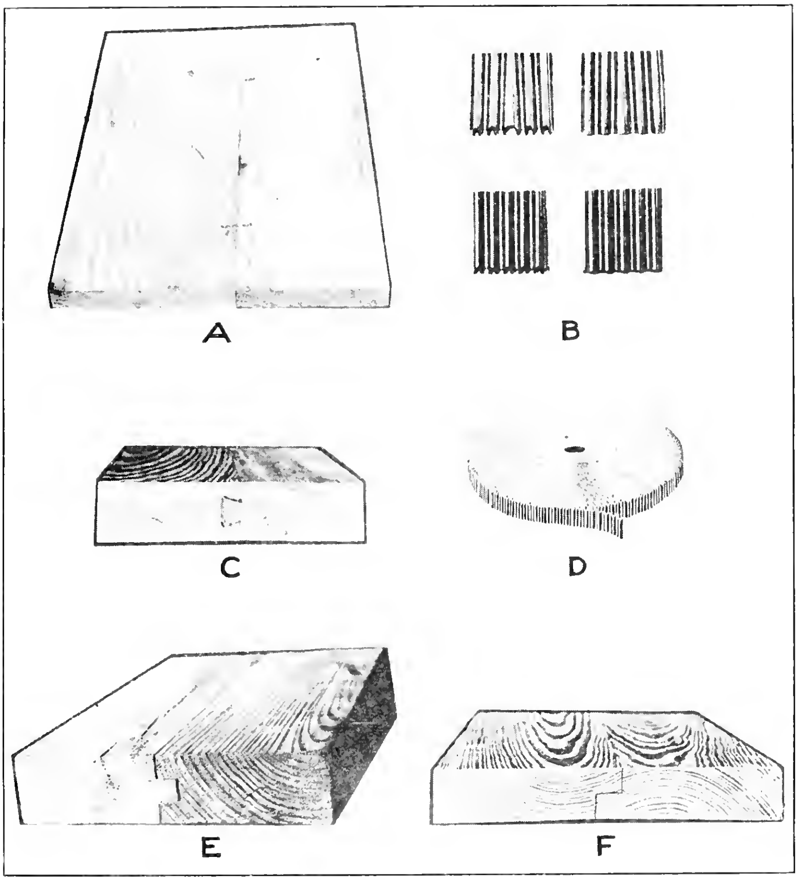
The low holding power of the nails driven into the end grain of the box ends in comparison with that of nails driven into the side grain is also a source of weakness in the style 1 box.

The locked-corner and dovetail (style 6) construction in which the ends and sides of the box are joined by a series of glued tenons is more rigid than the nailed construction. In style 6 boxes failures occur not only through the ends and sides splitting but also through the tenons breaking or pulling apart. Because of the relatively thin ends and the small nails used, failures sometimes occur through the top and bottom pulling off. Locked-corner and dovetail boxes are usually most efficient when the sides are of single-piece stock and the ends of a slightly greater thickness than the sides. Style 6 boxes usually require for the same service somewhat thicker sides and thinner ends than the nailed boxes of style 1. The thicker sides are required so as to avoid pulling the tenons apart by springing of the sides.

Each end of boxes of styles 4 and 5 is reinforced with two cleats. The chief purposes of the cleats are to permit the use of two or more pieces in the ends, to prevent splitting of the box, and to make better nailing possible. Some of the nails are usually driven through the sides into the cleats and some into the ends, thus increasing the nail-holding power and adding rigidity to the box. Such nailing also reduces the likelihood of the nails shearing the wood out at the ends of the boards or of splitting the wood holding their points.

When the character of the contents permits, placing the cleats inside the box decreases the length of the sides. If in such construction the nails are driven through the sides and cleats and are clinched, the resistance to the sides pulling off is greatly increased.

Inside cleats should be shorter than the depth of the box, so that in the event that the box sides and ends shrink the cleats will not protrude and thus cause an opening of the box top and bottom. Outside cleats, however, should be long enough to come nearly



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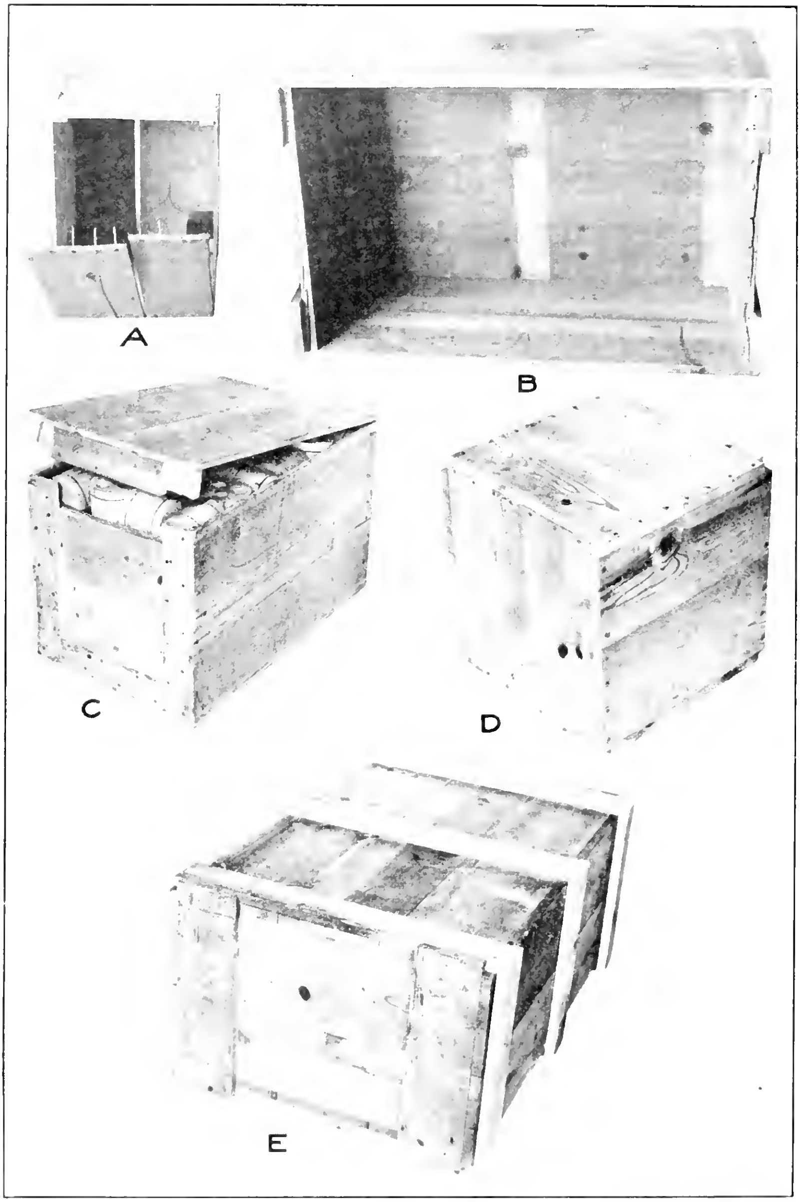
Different kinds of edge joints and fasteners: A, Use of corrugated fasteners; B, four types of corrugated fasteners; C, Linderman joint; D, coil of corrugated fastening material; E, tongue-and-groove joint; F, ship-lap joint



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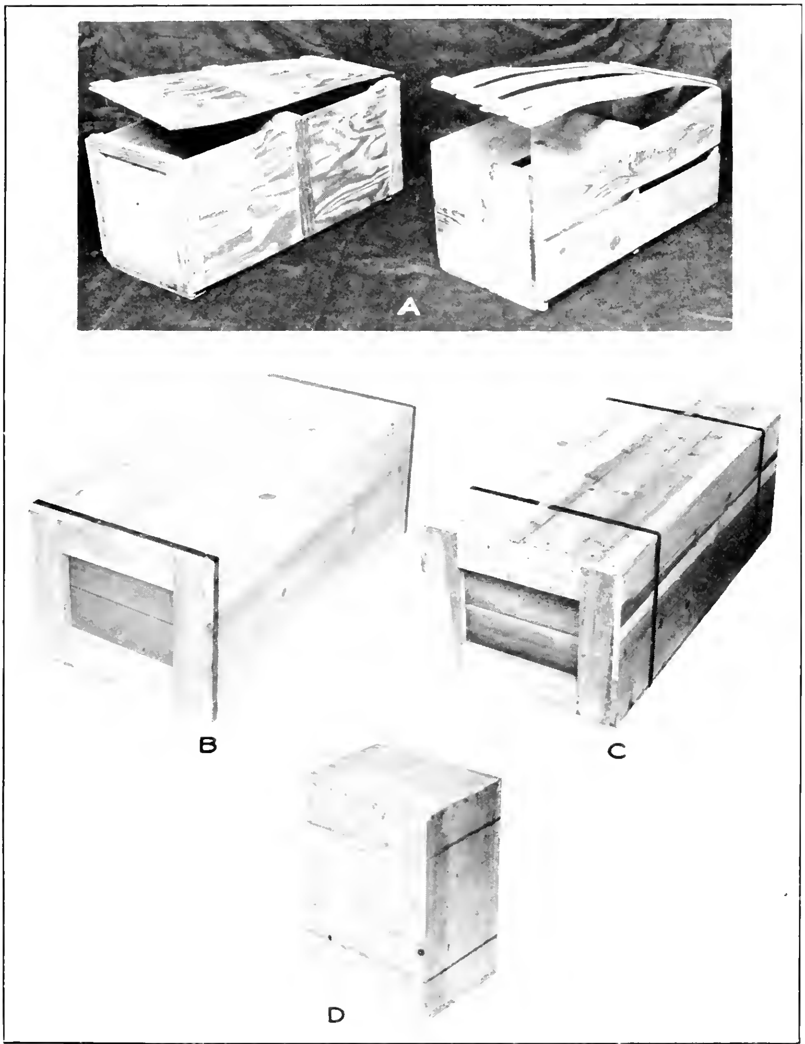
A and B, Typical failure of the ends of styles 4 and 5 nailed boxes by splitting at the nails; C, failure of style 2 box by splitting of end at edge of cleat; D, 3-way corner or so-called hardware type of box; E, box reinforced with wooden battens



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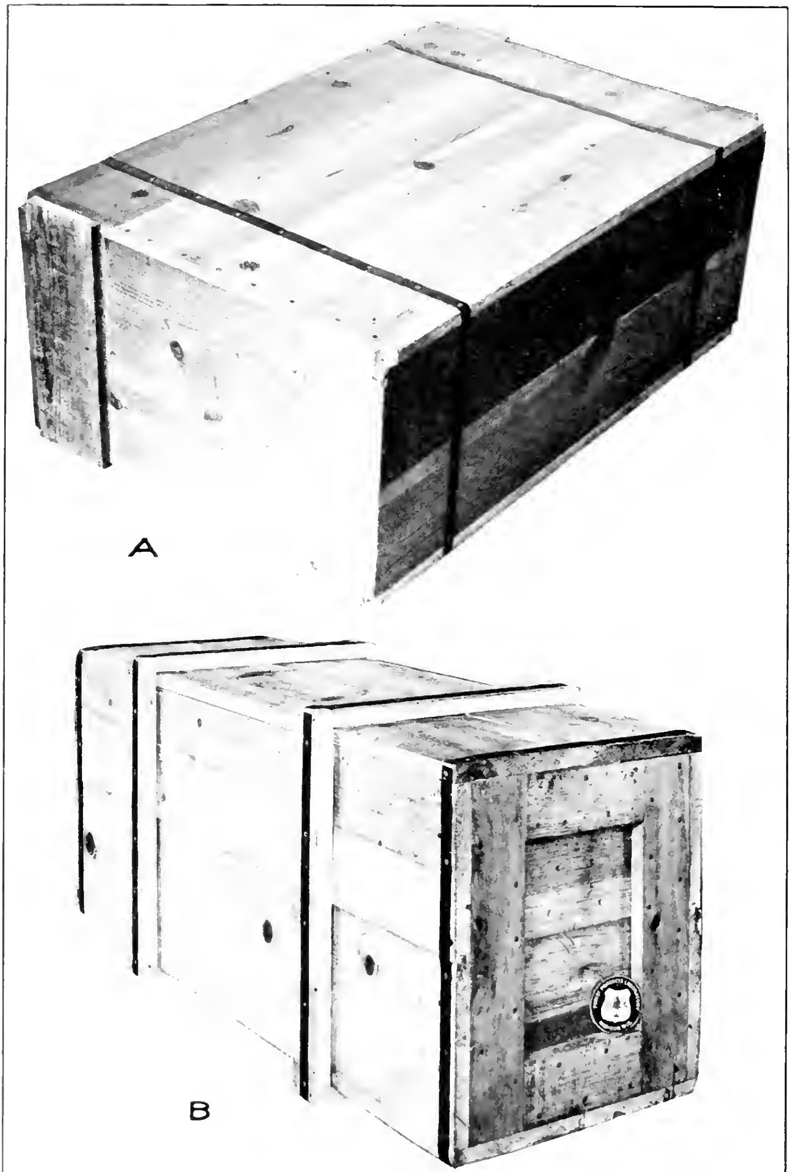
A, Standard boxes for fruits and vegetables; B, style 2 box with nailed metal straps; C, style 2 box with nailless metal straps; D, style 5 box bound with wires



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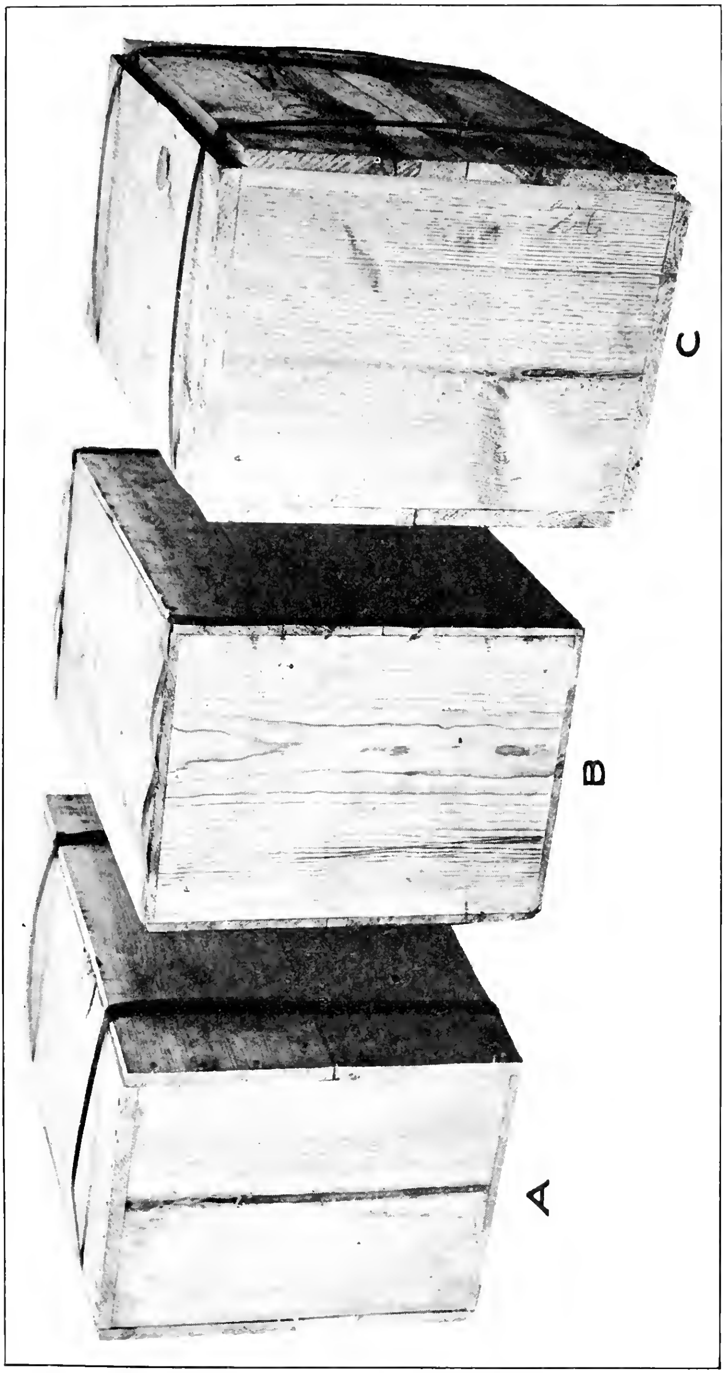
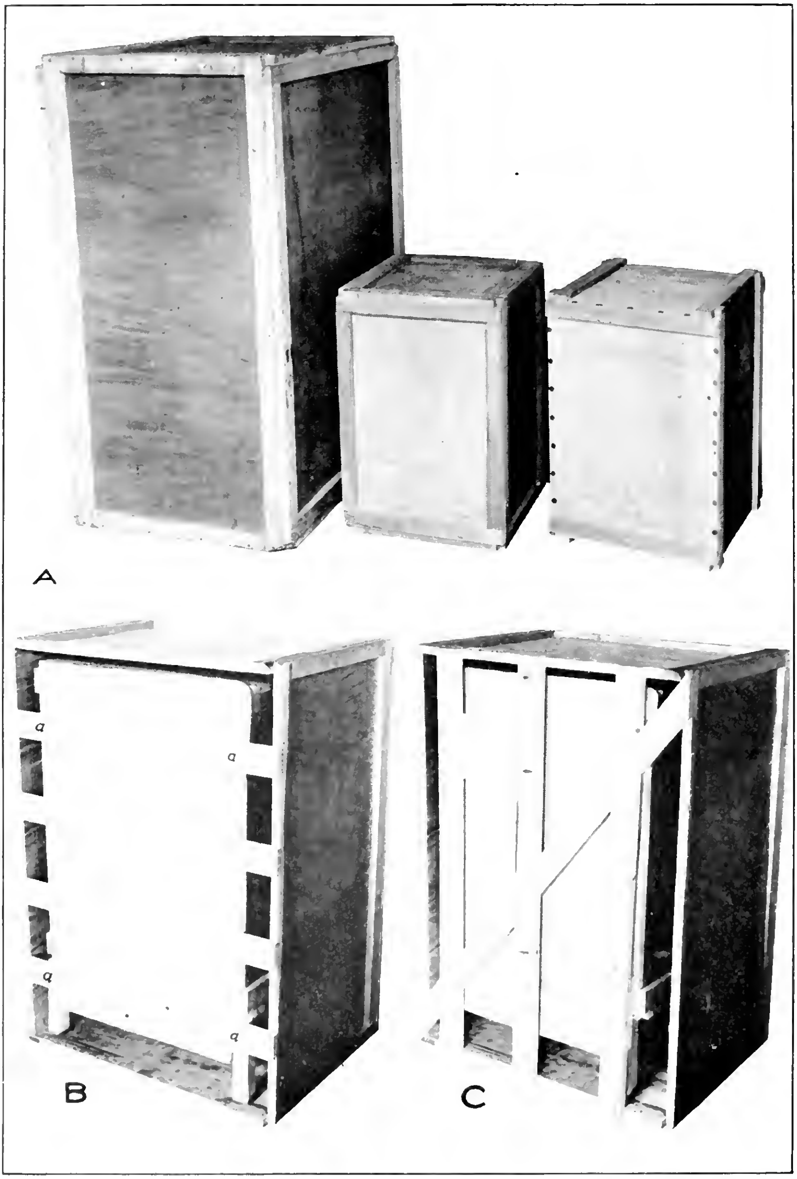
A, Nailed box reinforced with nailed straps placed away from the ends; B, a long box with battens and nailed metal straps. Such double reinforcing is desirable when straps alone will not give sufficient resistance to bending of sides, top, and bottom



Boxes made of lumber having 30 per cent or more moisture. These boxes were dried to 10 per cent moisture content, which resulted in the loose condition of the strapping. Boxes A and C were made from 3/4-inch and 1/2-inch stock. Box B was made from 5/8-inch and 3/8-inch stock



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Standard styles of plywood boxes: A, Cleated plywood boxes; B, plywood box having parallel slats on one face; C, open-face box reinforced with diagonal brace flush with the outer surface of the box top and bottom. They will thus increase the rigidity of the box top and bottom and assist in preventing the nails through the top and bottom from splitting the box ends. (Pl. 4, A and B.)

The two horizontal cleats on the ends of a style 2, 2½, or 3 box allow the nails holding the box top and bottom to be staggered in the box ends and cleats, thus increasing the rigidity of the top and bottom box faces in the same manner that the rigidity of the box sides is increased by the use of vertical cleats. If the placing of nails is divided between the horizontal cleats and the ends proper, the likelihood of splitting the box ends by the nails in the box top and bottom is reduced. Since in boxes having horizontal cleats some of the nails driven into the box ends are spaced farther from the ends of the top and bottom boards, the likelihood of the nails shearing out at the ends of the top and bottom boards is reduced. The ends of the boxes of styles 2, 2½, and 3 sometimes split along the inner edges of the horizontal cleats and fail by allowing the cleats with part of the end boards to pull away with the top or bottom. (Pl. 4, C.) Such failures are resisted by the strength of the end board in both tension and bending across the grain and by the reinforcing action of the vertical cleats. The styles 2 and 2½ boxes offer greater resistance to the foregoing type of failure than the style 3 box does, since more of the nails attaching the vertical cleats to the ends of the box may be placed close to the ends of these cleats. The style 2½ box has the advantage over the style 2 box in that during the nailing of the top and bottom, the notches on the vertical cleats support the horizontal cleats and take a thrust that would otherwise come on the nails joining the horizontal cleats to the ends.

Inasmuch as one of the chief functions of ends and cleats is to provide a means for adequately fastening the box parts together, it is desirable where maximum box strength is required to have the ends and cleats each of sufficient thickness to receive the nails. In order to save material, however, the ends of boxes of styles 2 and 2½ are sometimes made of relatively thin material reinforced with heavy cleats and the sides, top, and bottom are nailed to the cleats only. Boxes with such end construction are less rigid than boxes with thicker ends and have less resistance to splitting at the inside edges of the horizontal cleats. The nails in the ends of the sides, top, and bottom are closer to the ends of the boards in these parts and have less resistance to shearing out. Furthermore, such nails must be closely spaced in the cleats and consequently are more likely to split them. This construction, however, gives good service in boxes carrying relatively light loads.

The hardware type or 3-way corner box (Pl. 4, D) is very rigid. In this style of box the boards in all the faces are of the same thickness, and the edges of each face receive the nails holding the ends of the adjacent faces. Consequently it is necessary that the material be thick enough to prevent its being split by the nails. In service the hardware type box often strikes an object in such a manner that the entire weight of the commodity is transmitted to the nails as a direct pull, thereby loosening them. It is very difficult to nail boxes of this type so that the boards will not be knocked off in ordinary handling. The name "hardware type" appears to be a misnomer, since tests and experience indicate that such a box is not well suited for the shipment of hardware or other heavy commodities. A further objection to the hardware type is that, in closing it, the nails must be driven into four edges and from three directions.

Reinforcements

A number of different kinds of reinforcements have been devised to secure lighter and cheaper boxes and to strengthen containers against pilfering and against exceptional hazards.

Wooden battens around the box are among the oldest forms of reinforcement and are still used to some extent on export packages. (Pl. 4, E.) They may be placed on the inner or the outer surface of the box, at the extreme ends, or at some distance from the ends. They are objectionable for export boxes when placed outside because they increase the displacement, are likely to be knocked off, and often interfere with stacking. Where wooden battens are placed some distance away from the box ends and on the outer surface of the box, the battens should always be fastened with clinched nails. When securely fastened to the sides, top, or bottom, battens assist in preventing shear at the joints between the boards in these parts and thus increase the rigidity of the box. They also increase the resistance to puncture and render pilfering of the box contents more difficult. Securely nailed metal strips often connect the ends of the battens on adjoining faces of the box, thus forming a continuous binding which aids in absorbing shocks.

Thin cleats (pl. 5, A) are usually stapled to the ends of thin sides, tops, and bottoms of boxes used for the shipment of fruits and vegetables. These thin cleats are effective in preventing the thin lumber from splitting at the nails which fasten it to the box ends, from breaking under the nail heads, and from pulling away from the nails.

Metal straps and wires are the most common reinforcements for nailed boxes. They are lighter than wooden battens, do not appreciably increase the displacement, and interfere less with sliding and stacking. Usually where metal bindings are placed around the extreme ends of the box they are nailed. (Pl. 5, B.) Where metal straps are applied some distance from the ends they are held in place by drawing them tight and fastening their overlapping ends with a seal (pl. 5, C) or are spot welded. Overlapping ends of wire are usually twisted together to form a seal. (Pl. 5, D.)

Metal straps or twisted wire of two or more strands properly nailed around the box at the extreme ends, retard the pulling out of the nails from the box ends; assist in preventing the nail heads from pulling through the sides, top, and bottom; and aid in preventing the nails from shearing out of the ends of side, top, and bottom boards. The additional nailing required by metal binding increases the rigidity of the box. However, full advantage of nailed strapping is obtained only when the strapping is fastened with nails of the same size as those used in making the box. The tensile strength of flat strapping is reduced by driving nails through it; yet the reinforcement added to the box by the strapping nails offsets the reduction in tensile strength of the strapping.

Straps placed some distance from the box ends absorb part of the shocks which would otherwise be transmitted to the sides, top, or bottom. Such shocks are distributed to the various parts of the box through pull on the straps. This action relieves the direct pull of the box contents on the nails and reduces splitting or breaking across the grain of the sides, top, and bottom. Straps placed at some distance from the ends also allow the use of lower grade side, top, and bottom material than straps placed at the ends. Straps placed thus, however, are not so effective in preventing diagonal distortion as those nailed at the end of the box and are therefore less effective in reducing the shear on the nails in the ends of the sides, top, and bottom. Nailed straps placed away from the ends of the box (pl. 6, A) are less efficient than nailless straps similarly placed because of the weakening effect of the nail holes in the straps and because only short nails can be used except through the strap at the edges of the box or through straps applied over battens. (Pl. 6, B.) The nails at the box edges do not add sufficient strength to compensate for the weakening of the straps caused by the holes. Staples spanning the straps on large boxes are of value in holding the straps close to the box and preventing them from catching on objects.

Straps lengthwise of the box and perpendicular to the grain in the ends assist in absorbing shocks and thus help to prevent the ends being knocked out. Straps lengthwise of the box and parallel to the grain of the ends of uncleated boxes add little strength to the box.

A strap, placed away from the box ends, loses most or all of its efficiency upon breaking, whereas a failure at any point in a strap nailed around the ends of the box causes only a local weakness.

To be most effective, metal bindings, particularly the nailless variety, must be drawn tight enough to cut into the corners or edges of the box, and must be kept taut until they have served their purpose. For this reason the binding should be applied immediately before the box is shipped in order to avoid as far as possible any loosening effect that may be caused by the drying and shrinking of the lumber. (Pl. 7.)

Both metal bindings and wooden battens are effective means of reducing the weight of the box without sacrificing serviceability. Experience shows that the sides, top, and bottom of a nailed wooden box that is properly bound with metal bindings may safely be made 20 to 40 per cent thinner than those of boxes without such bindings. When straps are used in order to allow a reduction of the thicknesses of the sides, top, and bottom, it is necessary that the nailing be adapted to the reduced thicknesses of lumber. The use of strapping on a box normally does not justify any reduction in the thickness of the box ends.

The proper number of straps and method of applying them for any particular purpose depend upon a number of factors, the most important of which are the size of the box and the weight of its contents. Boxes carrying heavy loads and boxes carrying light loads are handled quite differently in service; consequently, although the straps required for the box carrying heavy loads should be larger, the size of the straps required is not in direct proportion to the weight carried in the box. The nature and value of the contents, the shape of the box, and the transportation hazards also have an important bearing on the number and size of straps needed. Rules for the selection and application of strapping are given in Appendix E.

CLEATED PLYWOOD BOXES

A cleated plywood box consists of single-piece plywood sides, top, bottom, and ends nailed to cleats. Figure 4 and Plate 8, A illustrate styles of cleated plywood boxes that have been adopted as standard by the Plywood Box Manufacturers' Association of America. The chief characteristics of cleated plywood boxes are: Light weight, high resistance to diagonal distortion, resistance to mashing at the corners,

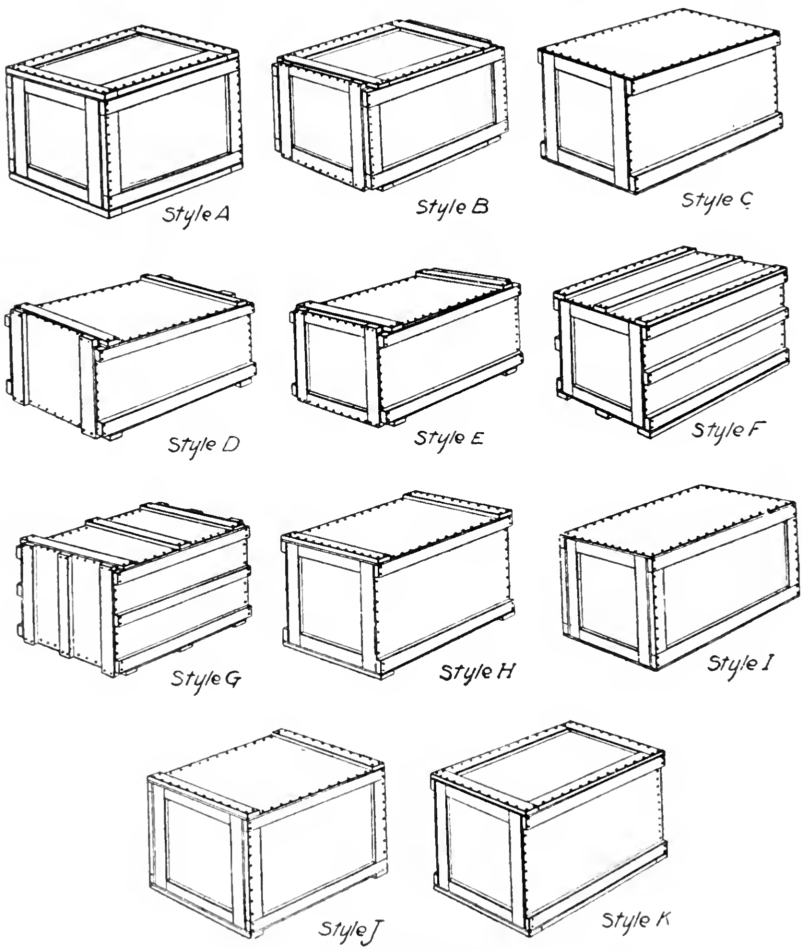


FIGURE 4.—Standard styles of cleated plywood boxes

and capacity to withstand severe tumbling and dropping. Cleated plywood boxes are neat in appearance, easy to handle, almost dust-proof, and are difficult to pilfer. The thin plywood springs easily and thus absorbs many of the shocks which would otherwise cause damage to the contents. Styles A, B, and D are those most commonly used. Styles A and B have four cleats on each face of the box and are often called full-cleated panel boxes. Styles B, D, E, and G have 3-way-corner construction.

DETAILS OF CONSTRUCTION

The high strength and rigidity of cleated plywood boxes result from the use of single-piece stock in the ends, sides, top, and bottom, and from the high resistance of plywood to splitting and to shearing or tearing away from the fastenings.

If the plywood on any face is replaced by slats of lumber placed parallel with an edge (pl. 8, B), the high resistance of the box to diagonal distortion and twisting is destroyed. If the commodity is fastened to these slats near the four corners of the box face (pl. 8, B, *a*) and the box is dropped on a corner, the stresses tending to cause diagonal distortion are resisted by the commodity, and damage to it is likely to result unless the commodity is able to resist diagonal, distortion stresses. If the open face is reinforced with a well-nailed diagonal brace as shown in Plate 8, C, the box has almost as much resistance to diagonal distortion as a box having all faces covered with plywood. If any one of the open faces is not braced by the commodity or otherwise the diagonal distortion that takes place in this unbraced face when the box drops on a corner will cause each of the faces to warp and the box to twist in a manner similar to the crate in Plate 20, A. A discussion of the influence of the commodity in preventing diagonal distortion and twisting of crates, given on page 35, applies also to plywood boxes.

NAILING

The nailing is one of the most important factors in the strength and rigidity of cleated plywood boxes. Much of the previous discussion of nailing on page 11 applies to cleated plywood boxes.

In making up the ends, sides, top, and bottom of most styles of cleated plywood boxes the plywood is attached to the wide faces of the cleats with nails or staples and in assembling the box the six panels so formed are nailed together. If too few fastenings are used in attaching the plywood to the cleats, the weaving of the box in service or the pressure of the contents or external objects on the plywood will either break the fastenings, pull them out, pull them through the plywood, or the plywood will split and shear away from them. If the nails or staples pass through the cleat and are clinched, they are not likely to pull out. Staples or large-headed nails are more difficult to pull through the plywood or to shear out than nails with small heads. Overdriving the staples or nails injures the plywood and reduces the strength of the joint.

If the nails holding the six panels together to form the completed box are of the wrong kind, number, or size, the box is weakened at the joints. The nails through the cleats and the plywood must be long enough to penetrate deep into the cleats on the adjacent box face; otherwise a greater number of nails will be necessary to prevent nail pull. Splitting of the cleats may be avoided by using nails as small in diameter as will permit driving.

Where nails are driven only through the plywood into the cleats on the adjacent face of the box, as in style D, the number of nails and the size of the nailhead are the important considerations in preventing the plywood from pulling away from the cleats. In such joints large-headed cement-coated roofing nails give good results. The loosening or pulling out of such nails may be overcome by using longer nails or a greater number of nails. Bending and breaking of the plywood at the nail line (pl. 9, A) may be decreased by increasing the number of nails. Failures because of the nailheads pulling through the plywood, or splitting or shearing the plywood out are also reduced by increasing the number of nails.

SIZE OF CLEATS

The primary functions of the cleats are to provide a means for securely fastening the box faces together and to reinforce the corners against mashing. Intermediate cleats are sometimes used, as in styles F and G, to reinforce the plywood against bending. The required sizes of the cleats along the edges of the box will vary with the nailing necessary to hold the box parts together. Such cleats should be free from defects that affect their nail-holding power or increase the tendency of the wood to split at the nails. Larger cleats are required where a single cleat is used along the edge of the box, as in style D, than where two cleats are used along each edge, as in styles A and B.

THICKNESS OF PLYWOOD

The thickness of plywood required will vary with the style of the box. The plywood in boxes with a single cleat along the edge bends under the impacts of the commodity and breaks at the nails fastening it to the cleats on the adjoining box side (pl. 9, A), whereas the plywood in a full-cleated box bends and breaks either along the inner edges of the cleats that are parallel to the face plies or at some distance from these edges. (Pl. 9, B.) The failures in plywood of a single-cleated box are localized around the nails, whereas in a double-cleated box the failures in the plywood are continuous along the edge of the cleat. Consequently a single-cleated box requires thicker plywood than a double-cleated one.

DIRECTION OF PLYWOOD

The best results in boxes having plywood consisting of three plies of the same thickness are obtained where the grain of the face plies for each box face is in the direction of the shortest dimension of that box face. This arrangement of the plies gives the plywood its greatest bending strength. In some boxes the bending of the plywood is an advantage because in bending the plywood absorbs shocks that would otherwise be transmitted to the box contents, but in other boxes the bending of the plywood is a disadvantage since it allows the contents to shift and to be damaged by rubbing. Plywood box sides having the grain of the face plies parallel with the width of the box face bend less under the impacts of the contents than if the grain is lengthwise of the face. The resistance of plywood to puncturing, shearing, splitting, and failure at the nails may be varied by changing the construction of the plywood (p. 68).

WIRE-BOUND BOXES

The wire-bound box is a lightweight type of shipping container that utilizes rotary-cut lumber, sliced lumber, or thin-sawed lumber in combination with cleats, wires, and staples. Unlike the sides of nailed boxes, the sides of wire-bound boxes are always of the same thicknesses as the box top and bottom, and usually the ends are of the same thickness as the sides. The thin material in the ends, sides, top, and bottom, springs and thus absorbs the shocks that would otherwise be transmitted to the commodity. The springing action enables the wire-bound box to withstand severe handling. The wires and staples hold the parts together and make pilfering of the box contents difficult.

In making wire-bound boxes two or more binding wires spaced at a determined distance are stapled by special machines to the side, bottom, side, and top box parts, consecutively, to form a mat. The end staples on each part span the binding wires and pass through the sheet material and, usually, into the end cleats. The staples over the intermediate binding wires are clinched on the inner surface of the sheet material A box in mat form as delivered to the shipper ready to be assembled with the end panels is shown in Plate 10, A. In assembling the box the mat is simply folded into position and the ends nailed or stapled to the inner surfaces of the side and bottom cleats. Closing the box consists of twisting together the ends of the binding wires. The box is easily opened by clipping the wires near the twist. The shape of the box may be readily varied to fit the contents. (Pl. 10, C.)

DETAILS OF CONSTRUCTION

The efficiency of a wire-bound box depends upon the combination of thicknesses of ends, sides, top, and bottom; number, size, and position of binding wires and staples; and end reinforcements. Failures in wire-bound boxes usually occur at or near the joints between the end cleats and the sides, top, and bottom, although occasionally failures are caused by the binding wires breaking, or the sides, top, and bottom puncturing or breaking between wires. The type of failure will determine which details of construction need to be changed to overcome the weakness.

Stapling

The stapling of end binding wires is one of the most important features with respect to the strength of the box. If the staples are of the wrong number or size, or improperly positioned, they may pull out, shear out at the ends of the boards, or split the cleats; or the sides, top, and bottom may break under the staples. Overdriving of staples causes the binding wires to mash the wood, thereby reducing the resistance of the sides, top, and bottom to breaking across the grain at the staples and under the wires.

Pulling out of staples from the cleats may be reduced by increasing the number of staples, by increasing their length, or by changing the position of the intermediate binding wires. Shearing out of the staples at the ends of the boards may be overcome by increasing the number of staples or the thickness of the sides, top, and bottom.

Splitting of the cleats at the staples is usually caused by the side pull on the staples of the wire and the sheet material. This failure is usually local and can sometimes be overcome by using more staples, thereby avoiding the localizing of the disturbing forces. In boxes carrying very heavy loads this type of failure may indicate that additional end reinforcements are needed.

The holding power of staples varies with the species of wood in the cleats and the moisture content of the wood, and with changes in moisture content after the staples are driven. (See p. 55.)

Proper positioning of staples over the end wires is important in order to prevent driving the staples into the joints since such driving causes splitting of the cleats or interference with the folding of the box. Since the staples over intermediate binding wires are clinched they are seldom a source of weakness, although they must be of proper length to provide a good clinch.

Thickness of Sides, Top, and Bottom

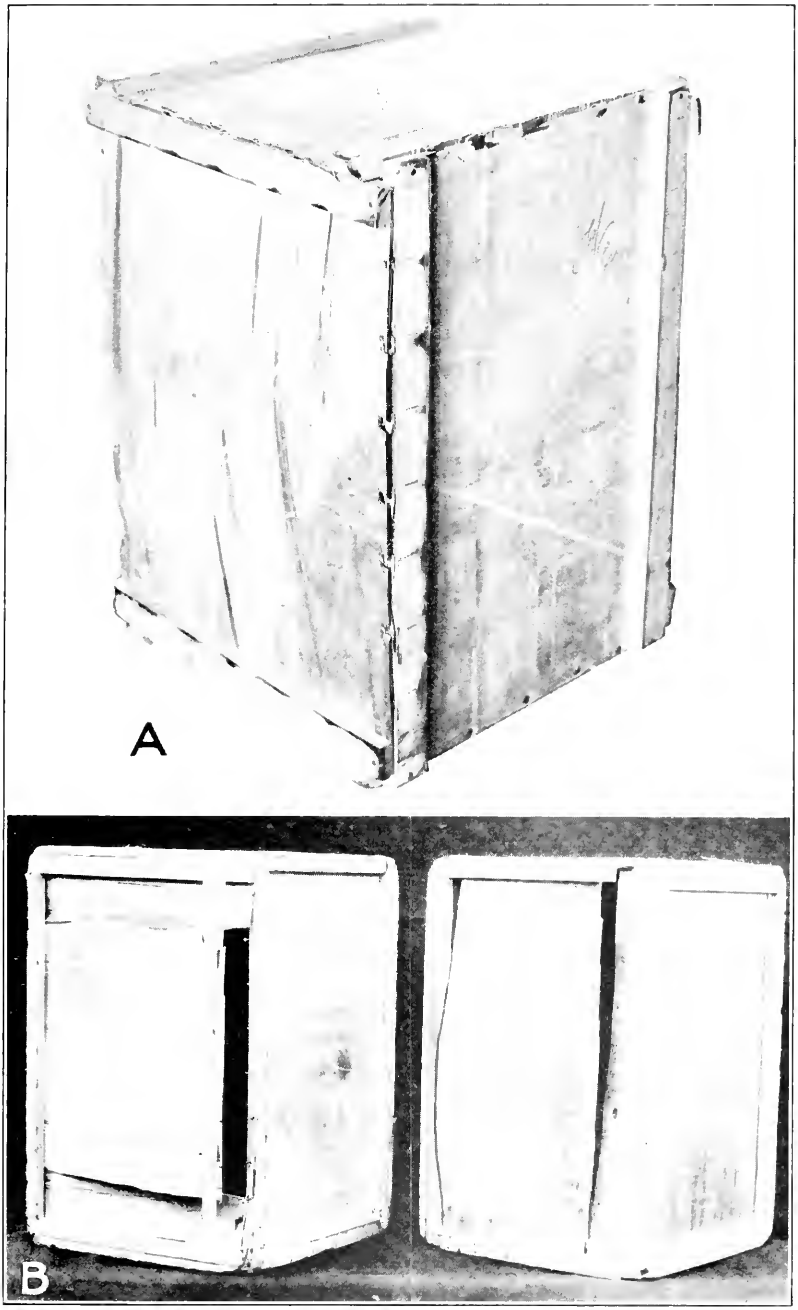
The thickness of sheet material required for a wire-bound box depends upon the species of wood, the spacing of the intermediate binding wires, the weight and nature of the contents, and the width of the box faces. If the material is too thin failures occur through the box mashing at the corners, through the sides, top, and bottom breaking across the grain at, or near, the end wires, or through the staples astride the end wires shearing out at the ends of the thin boards. In wire-bound boxes with wide faces the shocks of the contents, incident to rough handling, are distributed over a greater surface for the same gross weight, and consequently thinner sheet material may be used than in boxes with narrow faces. The wide faces also allow more stapling, so that failures caused by the staples pulling or shearing out at the box ends are less likely to occur.

The thickness of material required to prevent mashing at the box corners is determined largely by the weight of the contents, although the size of the box influences the stresses indirectly through its effect on the method of handling. The relation of the thickness of the box material to the species of wood, to the size of the box, and to the weight of its contents may be approximated by the equations given in Appendix E.

Damage to the commodity from the springing of the box sides, top, and bottom may be avoided by increasing the thickness of the material, by increasing the number of wires or changing their position, or by using intermediate rows of cleats, as shown in Plate 11, A. Such cleats also afford reinforcement against puncture. Intermediate rows of cleats are sometimes useful in preventing damage by serving as separators between units of the commodity. These cleats when serving as separators often permit decreasing the thickness of the box parts.

Size and Spacing of Wires

The size and the spacing of the wires are important in determining the thicknesses required for the sides, top, and bottom, and in holding these parts together. The intermediate wires reinforce the sides, top, and bottom against breaking across the grain and also against springing, thereby retarding the loosening, pulling out, and shearing out of the staples. If, however, too many intermediate wires are used the shocks in handling are not absorbed by the springing of box sides, top, and bottom. Greater stresses, therefore, are transmitted to the joints, and failures are more likely to occur through the knocking out of the ends or through the mashing of the box at the corners. The number of wires required for a satisfactory box depends upon the thickness of the sheet material, which, in turn, is determined by the size of the box, weight, and nature of its contents. The size of wires required varies with the number used, but the sum of their total cross-sectional area depends upon the weight of the box contents. The relation of the number and size of wires to the thickness of the



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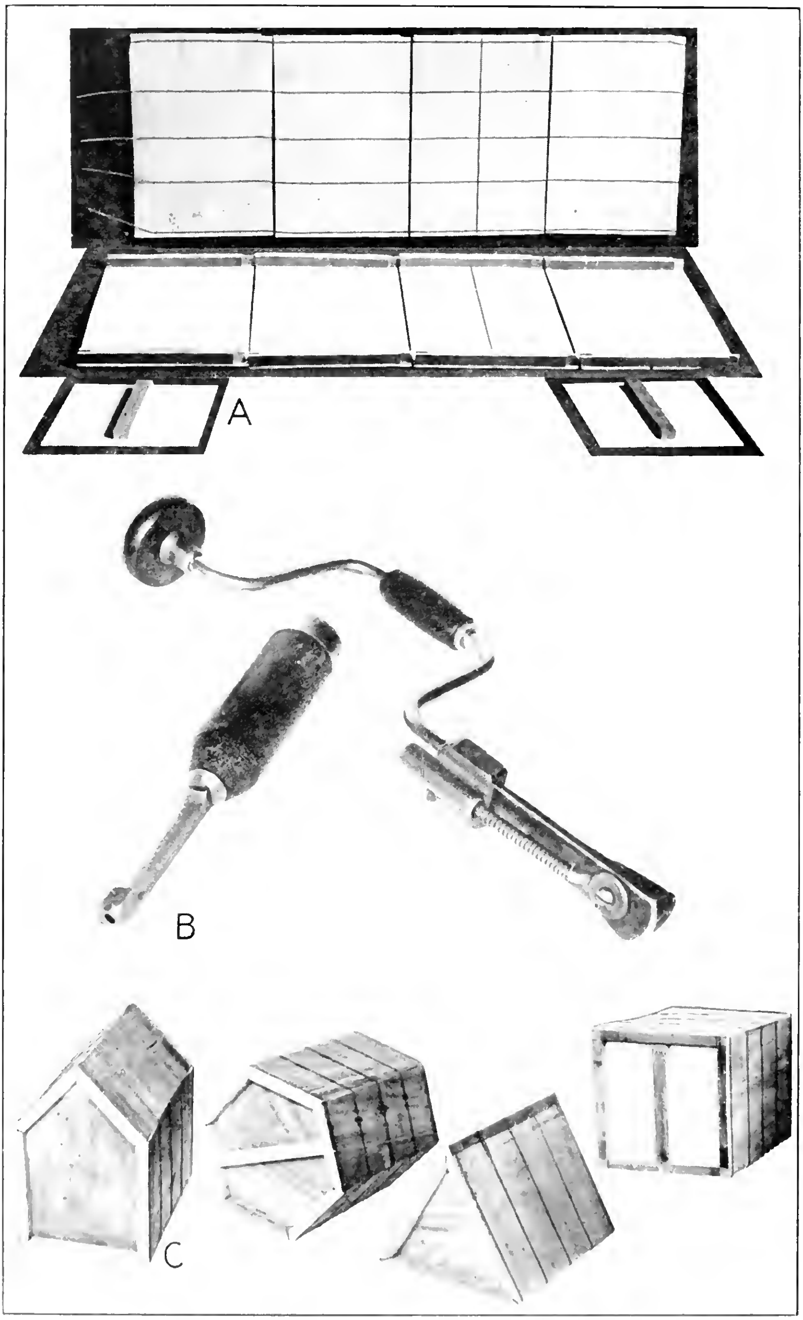
A, Characteristic failure of single cleated plywood box; B, characteristic failures of cleated plywood boxes



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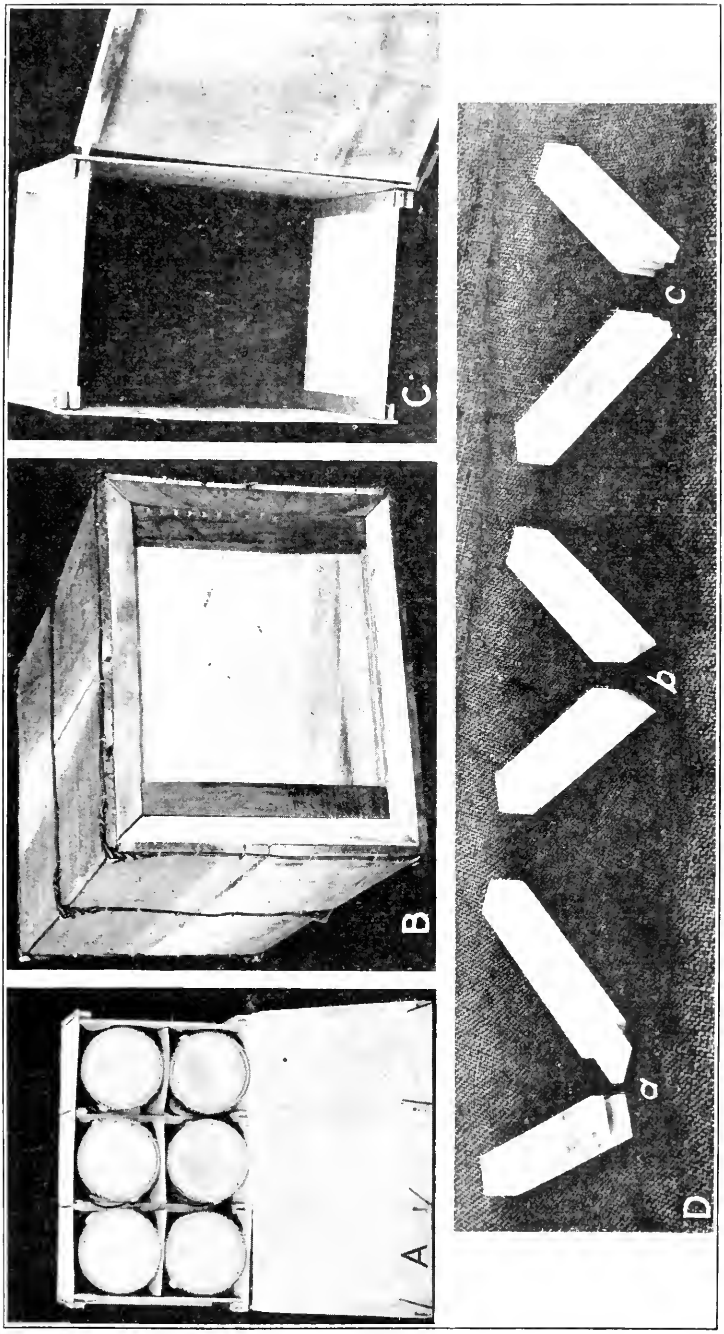
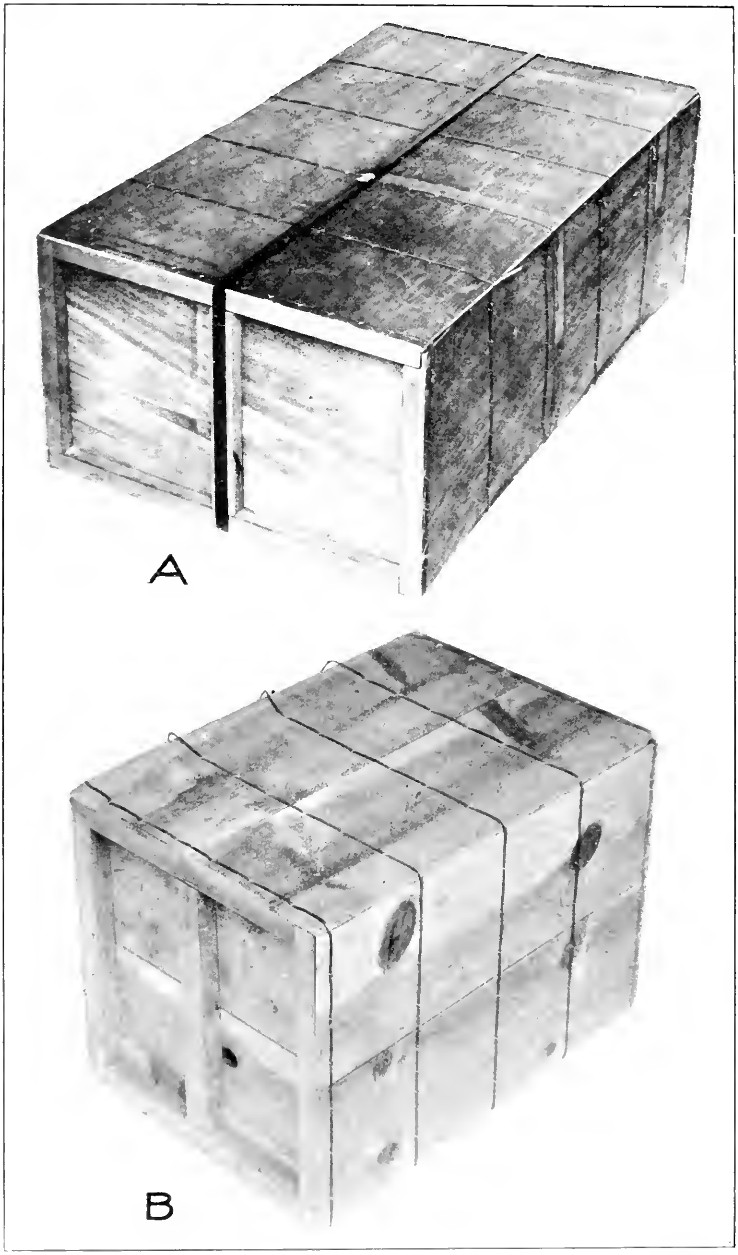
A, Wire-bound box as delivered from fabricating machine ready to be assembled; B, standard tools for twisting the ends of wires in closing wire-bound boxes and crates; C, wire-bound boxes of various shapes



A, Wire-bound box having intermediate rows of cleats; B, wire-bound box showing wires joined by "loop ties"; C, liners used to reinforce end boards; D, cleat joints commonly used in wire-bound boxes; (*a*) mortise and tenon; (*b*) plain miter; (*c*) step miter



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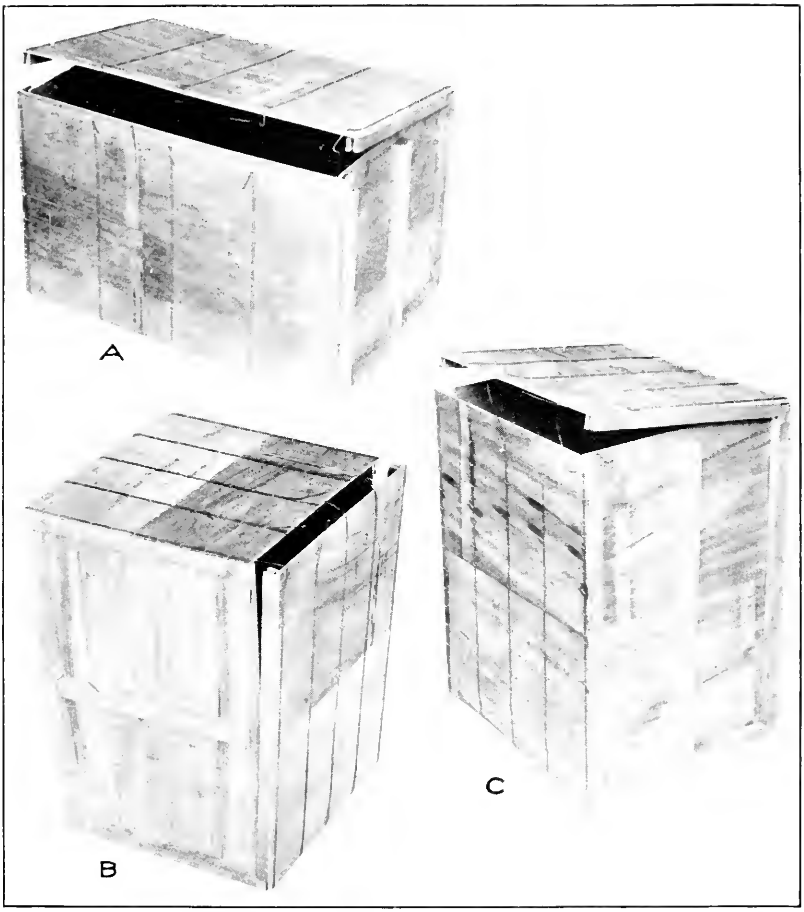
A, Wire-bound box reinforced with metal strap lengthwise of box; B, wire-bound box made of low-grade resawed lumber



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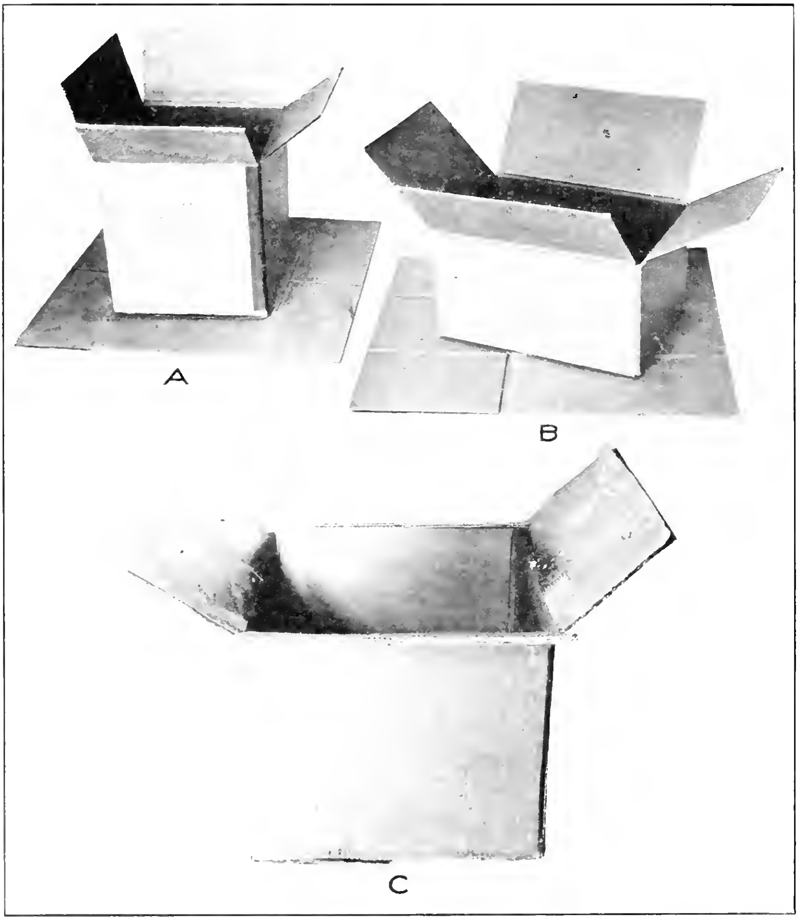
Wire-bound boxes with the grain of the sheet material in different directions: A, The grain of the boards in the sides, top, and bottom and end runs in the direction of the longest dimension; B, the grain of the boards in the sides, top, and bottom runs in the direction of the shortest dimension; C, the grain of the boards in the sides, top, bottom, and ends runs in the direction of the shortest dimension



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One-piece slotted fiber boxes: Corrugated fiber box A and solid fiber box B, folded flat and set up; C, double thickness corrugated fiber box material may be approximated by the equations and curves given in Appendix E.

Usually the end wires and the adjacent intermediate wires need to be spaced closer than the other wires. When placed near the box ends the adjacent wires are better able to absorb the shocks of the contents which tend to bend the thin boards in the sides, top, and bottom and to pull them away from the staples, or to break the sides, top, and bottom under the end-binding wires. Furthermore, the wires near the box ends are in a better position to relieve the direct pull of the contents on the staples astride the end wires. The exact positioning of the wires is dependent upon the nature of the box contents. The wires may sometimes need to be so spaced that when they are drawn tightly in closing the box they spring the box sides, top, and bottom against the commodity in such a way as to retard its shifting and thereby reduce the outward thrust on the box ends. Again, where the weight of the box contents is concentrated at points on the box faces instead of being uniformly distributed over these faces, the intermediate wires may need to be spaced in direct line with the points of contact so as to better reinforce the thin box sides, top, and bottom against springing and breaking across the grain.

Closing the Wire-Bound Box

Failures due to the wires pulling apart at the closure are usually the result of improper twisting. The best closures are obtained by using special tools which have been developed for twisting the wires. (Pl. 10, B.) The wire should be soft enough not to break when the ends are twisted together, and, as a precaution against pilfering, hard enough so that it can not be untwisted and retwisted without breaking. After the twist is made it is bent down alongside the wire, as shown in Figure 5. This box may be readily opened for inspection and easily reclosed. The box is opened by clipping the wires either near the twisted ends or along the opposite top edge of the box. The top is then lifted like the lid of a trunk. The box is reclosed by splicing the wires with short pieces and twisting the ends together as in making the original closure. Figure 6 illustrates a convenient patented device for splicing the wire. The end of the wire on top of the box is inserted into the coiled end of the splicing wire and then bent to form a hook which fits into the other half of the coil and completes the splice. Plate 11, B illustrates a type of wire-bound box having the wires joined together when assembling the box by means of "loop ties" at their ends.

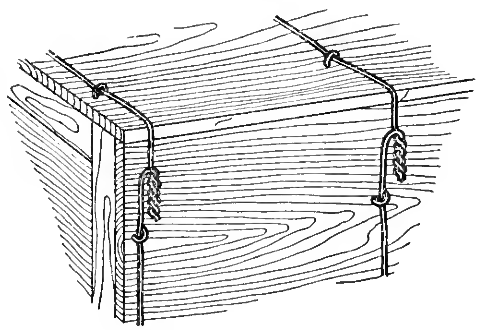


FIGURE 5.—Properly made wire-bound box seal

Ends, Cleats, Battens, and Liners

The end sheets of wire-bound boxes are usually of the same species and thickness of material as the sides, top, and bottom, although thick ends are sometimes used in boxes carrying heavy loads. In order to facilitate the production of wire-bound boxes by special machines and to reduce the costs the dimensions of cleats have been standardized. Until recently one size for cleats,[4] approximately 13/16-inch by 7/8-inch material, was commonly used for boxes of all sizes in combination with seven thicknesses of sheet material, four sizes of wires, and four sizes of staples. In 1928 improvements were made so that the machine for fabricating wire-bound boxes could be set up to use several sizes of cleats within the range of nine-sixteenths to 1⅛ inches in thickness, and several lighter (one-sixteenth and one-twelfth inch) thicknesses of sheet material and sizes of wires and

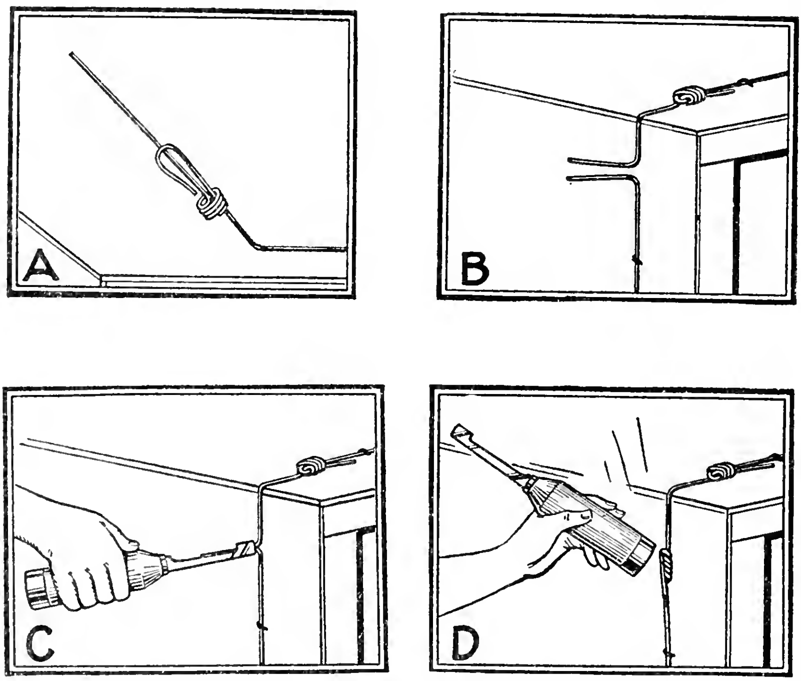


FIGURE 6.—The wire-bound box may be readily opened for inspection and easily reclosed: A, Insert end of wire on top of box into coiled end made by splicers and bend box wire into form of hook as shown; B, pull tight so that end of hook fits into other half of coil; C, twist the two wire ends together until excess length is cut off; D, knock twist against side and box is then closed

staples. The ends of the cleats are usually put together in a mortise-and-tenon joint, such as is shown in Plate 11, D, *a*, although the plain miter (pl. 11, D, *b*) and step miter (pl. 11, D, *c*) are sometimes used. Mitered joints permit driving the staples close to the corner of the box, thereby reducing the tendency for the wire to slip off at the corner.

Figure 7 illustrates various arrangements of battens for end reinforcements that have been adopted by the Wirebound Box Manufacturers' Association. Styles A, C, D, F, T, and X are most commonly used. The A battens reinforce the top and bottom cleats against

[4] Sizes of other parts commonly used are: Thickness of sheet material: One-eighth, one-sixth, three-sixteenths, seven thirty-seconds, one-fourth, five-sixteenths, and three-eighths inches. Binding wires: 12, 13, 14, and 15 gage (steel wire gage). Staples: Over end wires, 16-gage (steel wire gage) by 1⅛ inches and 1¼ inches; over intermediate wires, 18 gage (steel wire gage) by 7/16-inch and 9/16-inch.

breakage. If nails are driven through the top and bottom cleats into the batten the end sheets are strengthened against breakage across the grain. The D battens reinforce the side cleats against breakage and permit long nails to be driven through the mat to reinforce the staples.

Battens sometimes have a tongue on the edge and on the ends to fit into grooves provided in the edges of the cleats.

The end boards are sometimes reinforced on the inner side and near their ends with thin strips of lumber called liners, through which the nails or staples are driven in attaching the box ends to the cleats. (Pl. 11, C.) These liners assist in preventing the end boards from splitting and the fastenings from pulling through the thin end boards or shearing out at the ends of these boards.

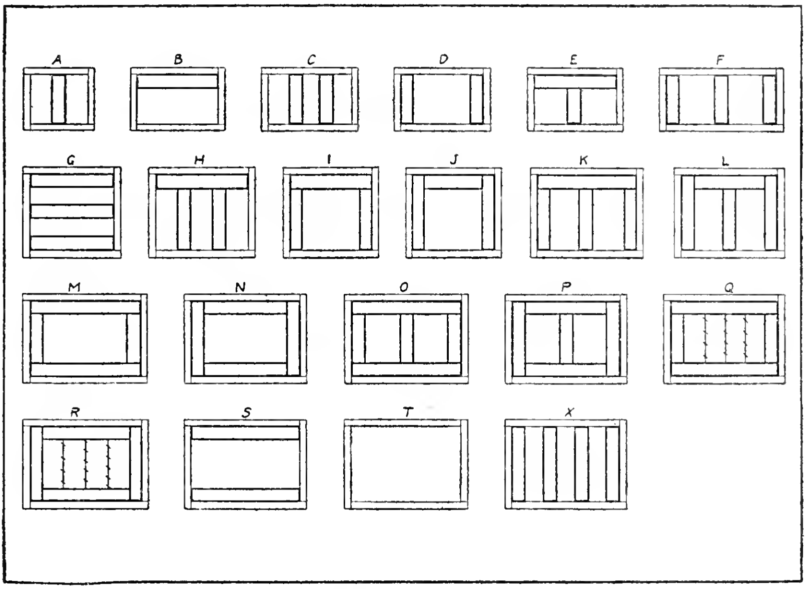


FIGURE 7.—Arrangements of end battens for wire-bound boxes

STRAP REINFORCEMENTS

Metal straps or wires placed around the box lengthwise (pl. 12, A) afford effective reinforcement of the ends and cleats. Straps applied in this manner prevent the ends from being kicked out, assist in preventing the pulling out of staples, and reinforce the ends and cleats against breakage across the grain. Straps may be applied lengthwise around boxes either with or without battened ends.

NUMBER OF PIECES OF BOX PARTS

The number of pieces in the sides, top, and bottom is the principal factor in the resistance of a wire-bound box to diagonal distortion. Since wire-bound boxes with a number of narrow pieces in the sides, top, and bottom distort easily they absorb the shocks of transportation and are consequently better adapted than boxes with wide pieces for shipping articles which are not damaged by shifting or rubbing.

Direction of Grain

Wire-bound boxes are usually made so that the grain of the boards in the sides, top, and bottom runs in the direction of the longest dimension of the box (pl. 13, A) although in large export boxes the grain of the boards is sometimes run parallel to the shortest dimension. (Pl. 13, B, and C.) Where the grain of the boards parallel one of the shorter dimensions the ends, cleats, and binding wires are longer and the sides, top, and bottom are wider than where it parallels the longest dimension. Placing the boards with the grain in the direction of one of the shorter dimensions increases the ability of the box to withstand outside pressure, such as from rope slings or from stacking, but reduces its resistance to the impacts by its contents. The cleats, being longer, are more easily broken, and consequently better end reinforcements are required.

Because of its many wire reinforcements the wire-bound box is well adapted to the use of low-grade sawed lumber either from hardwoods or softwoods. Plate 12, B illustrates a wire-bound box made with knotty resawed lumber in the ends, sides, top, and bottom and with clear hardwood cleats and battens.

CORRUGATED AND SOLID FIBER BOXES

Two types of fiber board, corrugated and solid, are in common use for making boxes. The single-thickness corrugated type consists of a sheet of paper board that after being corrugated, is pasted with silicate of soda (a mineral glue) between two outer flat sheets of paper board termed "test liners". Double-thickness corrugated-fiber board is a silicate-pasted assembly of three sheets of paper board and two sheets of corrugated board. Solid fiber board is formed by pasting one or more sheets of chip board between two test liners.

Corrugated fiber sheets are usually made from straw pulp or from pine or chestnut wood pulp. The outer plies or test liners of both corrugated and solid fiber boards contain comparatively long-fibered wood pulp, either new or repulped, and a variable proportion of shorter-fibered pulp obtained from the cheaper grades of waste paper. The inner plies of solid fiber board consist of chip board prepared from waste papers of the lowest grade. The strength of either type of fiber board can readily be adjusted within limits to different requirements through varying the thickness, number, and quality of the component plies.

In the manufacture of a box the corrugated or solid fiber board is slotted and is creased, or scored, to facilitate bending. Plate 14, A and B, shows a 1-piece slotted carton of each type folded flat for shipment and set up ready to receive its contents. The one vertical joint in a corrugated fiber box is made at the factory with gummed tape (generally cambric, but occasionally paper) and that in a solid fiber box with flat stitching wire.

Fiber boxes have certain characteristics that make them especially suitable for use in shipping a large variety of products. They are light in weight, easy to handle, neat and attractive, and almost dust proof. As received from the manufacturer in the knock-down condition they require small storage space and are easy to assemble. The corrugated is better adapted than the solid type for the shipment of glassware and other light and fragile articles because the corrugated board absorbs shocks better than the solid. Boxes made of double-thickness corrugated boards (pl. 14, C) have greater shock-absorbing qualities than boxes made of single-thickness corrugated board. The solid fiber type, however, has greater resistance to rough handling

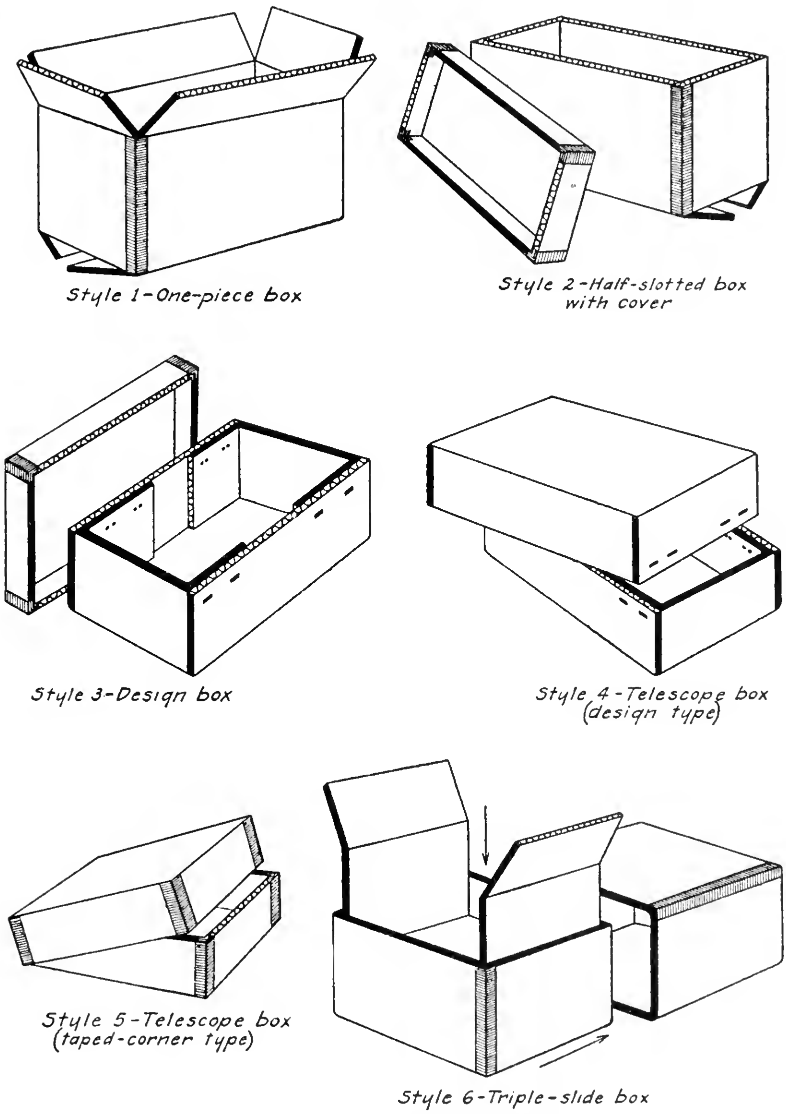


FIGURE 8.—Styles of corrugated-fiber boxes

and to wear as a result of sliding and is, therefore, better adapted for use in shipping heavier and less fragile articles. Fiber boxes are made in various styles, as shown in Figures 8 and 9. The 1-piece slotted carton, styles 1 and A, is in more general use than any of the other styles.

DETAILS OF CONSTRUCTION

Scoring

The strength of a corrugated or a solid fiber box when properly closed depends very largely on the quality of the fiber board and the moisture condition of the board at the time of scoring and the manner in which the board is scored. If the dies used to form the scores are of the wrong size or form and make the scores too deep or too shallow, or if the bends are too abrupt, the strength and serviceability of the

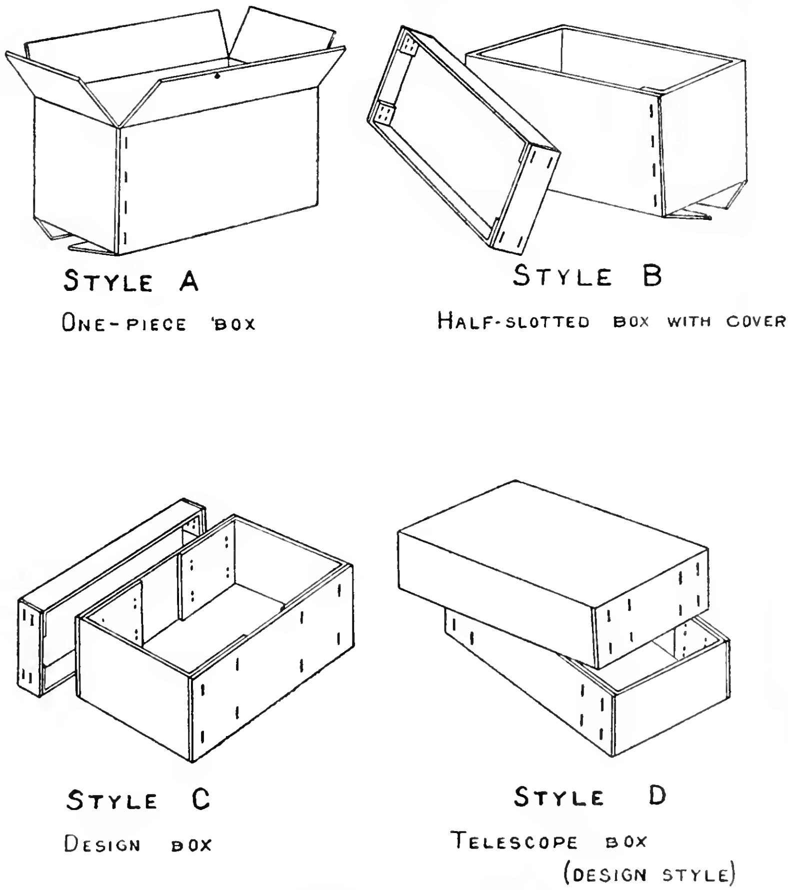


FIGURE 9.—Styles of solid-fiber boxes

box is greatly impaired. Any slight cracking or breaking along the scores when the box is folded into position indicates that the scoring has not been done properly, that the board did not have the proper moisture content at time of scoring, or that the test liner is of poor quality and the box will not have the maximum capacity to withstand rough handling. No matter how strong the fiber board may be nor how well it has been scored, failures in boxes that are properly closed usually occur at the longer scores of the smallest face (usually the horizontal end scores).

Direction of Grain of Fiber Board

A sheet of paper board has a definite direction of grain much like that of a piece of wood. This direction is determined by the position of the fibers, most of which arrange themselves parallel with the direction in which the sheet passes through the machine in the process of making the paper board. In the formation of paper board, either solid or corrugated, the component sheets are usually pasted with their grains parallel. As a consequence, fiber sheets and fiber boards are stronger in tension parallel with the grain than across it, and have greater resistance to tearing across the grain than parallel to it. Boxes made with the grain of the board perpendicular to the longer scores of the smallest face usually resist a greater amount of rough handling than those made with the grain of the board parallel to these scores. Solid fiber boxes made with the grain of the board perpendicular to the horizontal scores also resist greater stacking loads when stacked in the normal position than those made with the grain parallel to these scores. Because of the stiffening effect the corrugated-fiber boxes, however, resist greater stacking loads when the corrugations are perpendicular to the horizontal scores, although the grain of all the component sheets may be parallel to the horizontal scores.

Sealing or Closing the Box

The proper sealing of a fiber box is as important as the design and construction of the box itself. Three methods of sealing the 1-piece slotted carton are in common use, (1) pasting the flaps together (usually with silicate of soda), (2) covering all outer seams with gummed paper tape, and (3) stitching the flaps together along all seams with metal staples. (Pl. 15.) The method of sealing is of little significance as regards the strength and serviceability of the box. The principal consideration is that the sealing must be done in a thorough manner.

When the sealing consists of pasting the flaps together, the properties of the adhesive should be such that it can be spread evenly over the entire surface of the flaps and permit the flaps to be brought together before it takes its initial set and can dry quickly thereafter. Unless pressure is applied to hold the flaps in contact while the adhesive sets, proper sealing will not obtain. Special machines are sometimes used for applying pressure in sealing with adhesives. The use of an excessive amount of adhesive prolongs the drying and the time the flaps must be kept under pressure.

Sealing tape (strips not less than 2 inches wide) applied at the seam of the outer flaps only, does not produce so good a seal as pasting the flaps together. Boxes with sealing tape applied at the seam of the outer flaps and also along the horizontal end scores, however, withstand more rough handling than boxes sealed only by pasting the flaps together. The lower rigidity of the seal reduces the stress on the scores, and the tape reinforces the scores. The tape-sealed boxes do not hold their shape so well as the boxes sealed with silicate of soda. Sealing tape is sometimes applied near the center of the box and at right angles to the seam of the outer flaps but is less effective in reinforcing the box than tape applied lengthwise of the seam.

Metal staples produce fully as good a seal for solid fiber boxes as either silicate of soda or sealing tape, provided all outer flaps are stapled to inner flaps at or along all joints in the outer flaps and the staples are spaced not more than 2½ inches apart. Corrugated boxes require staples of larger or wider wire than solid fiber boxes to prevent the staples from pulling through.

No matter what method of sealing is employed, failure at the seal rather than at the scored edges indicates that the sealing has not been properly done.

Length of Flaps

To obtain the maximum resistance to rough handling for a given quality of material, the ends of the outer flaps of fiber boxes should meet or overlap and the ends of the inner flaps should meet or the space between their ends should be filled with a sheet of fiber board which should be fastened securely to the outer flaps in sealing the box.

Reinforcements

Paper tape applied on the outside of the box and along the scores (pl. 16, A) reinforces the characteristically weak points of a fiber box and greatly increases the resistance of the box to rough handling. Taping scores on the inside is usually of less value as a reinforcement than tape applied on the outside. The resistance of the box to loss of contents through failure of the scored edges may be further increased by binding the boxes with metal straps (pl. 16, B) applied under tension. Damage to the contents through the box mashing at the corners or through the puncturing of the ends and sides may be readily reduced by corner or other interior pads or cushions that support and protect the commodity. (Pl. 16, C.)

Recommended Practice

The recommended designs of fiber containers for various uses are given in the specification set forth in Appendix G.

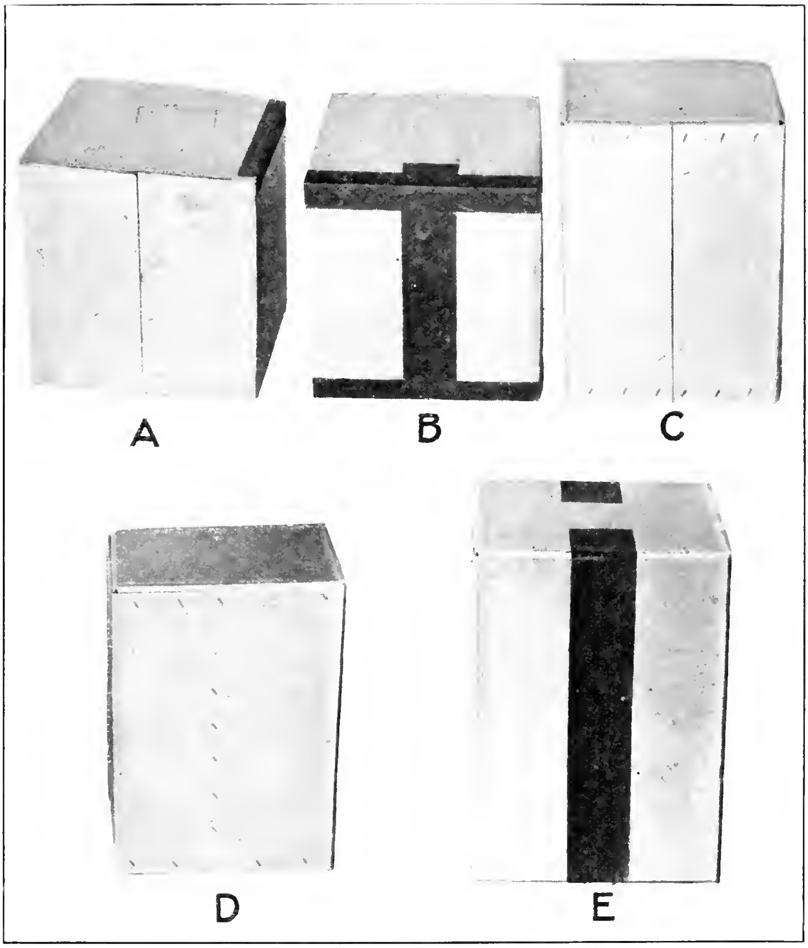
NAILED CRATES

The two principal styles of nailed crates suitable for general use are the 3-way corner, and the box style. Both are shown in Plate 17, A and B. The outstanding characteristics of these constructions are great resistance to crushing and mashing at the corners and, where properly braced, high rigidity and high resistance to rough handling. They are easy to handle, easy to manufacture, and their strength and rigidity may be readily adjusted to different requirements by varying the details of construction.

DETAILS OF CONSTRUCTION

Edge Members

The edge members form the foundation upon which the rest of the crate is built. They must be of sufficient size and strength to permit adequate fastening of the various parts and to support the loads and shocks encountered in storage or transit. Edge members that are approximately square produce stronger crates than thin members of the same cross-sectional area. Square members allow the use of large nails and also permit the nails to be staggered, which reduces the chance of failure in service by splitting. Square members, however, increase the displacement of the crate and afford less protection



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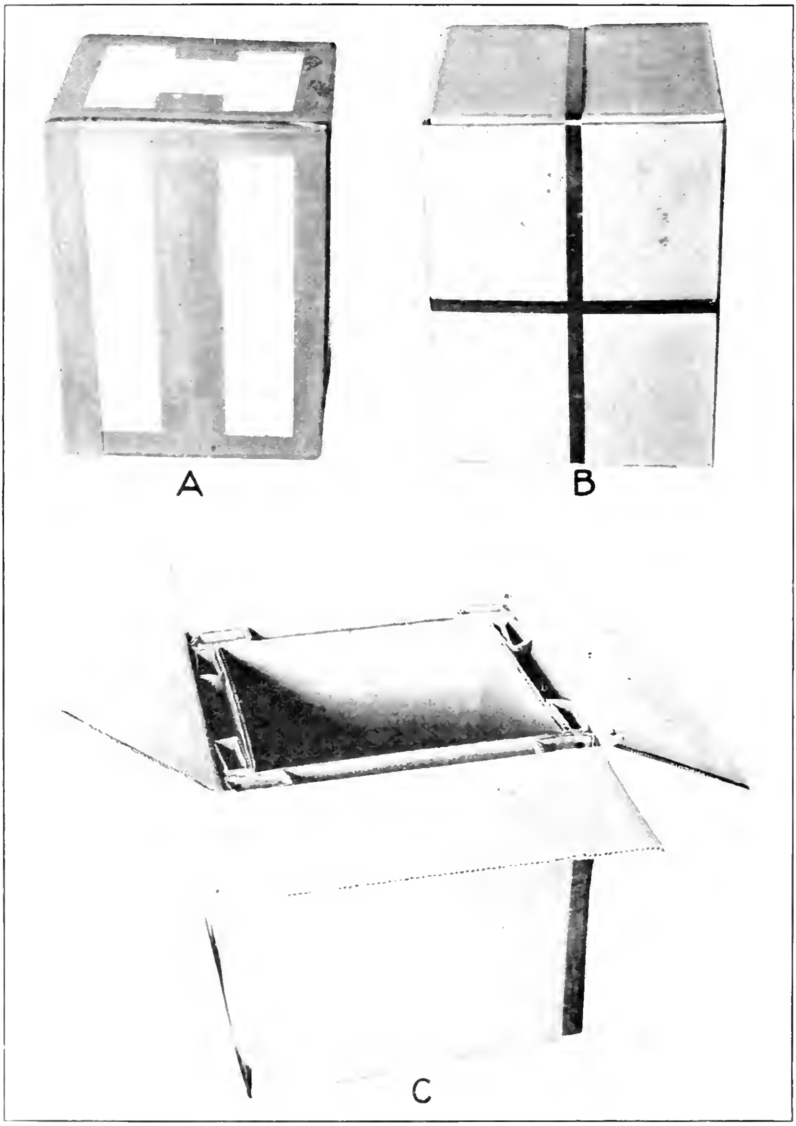
Methods of sealing 1-piece slotted fiber boxes: A, Outer flaps glued to inner flaps; B, sealing tape applied on joint of outer flaps and along horizontal end scores; C and D, flaps stitched together with metal staples; E, sealing tape along joint of outer flaps only



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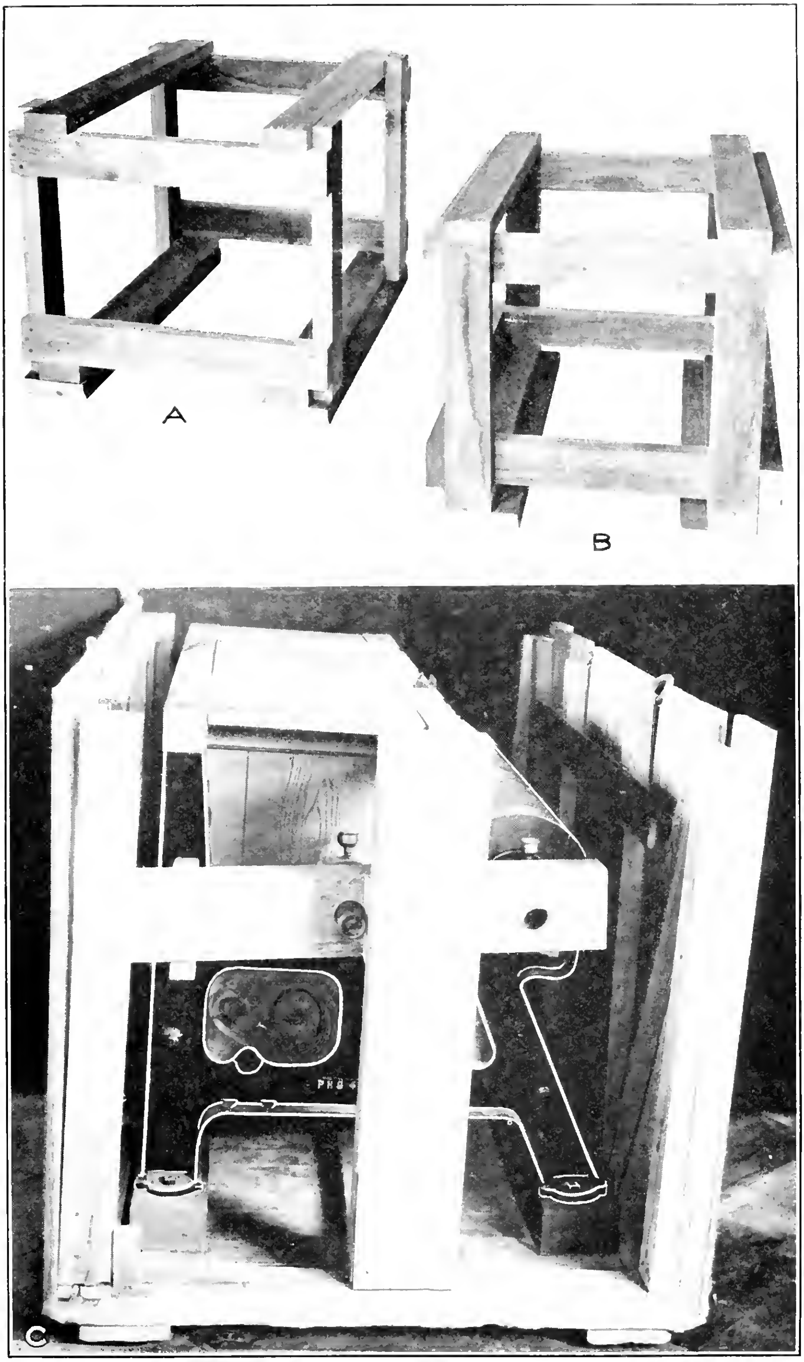
Methods of reinforcing fiber boxes: A, Tape applied along edges; B, sealed metal strapping applied in two directions; C, interior pads to protect the commodity



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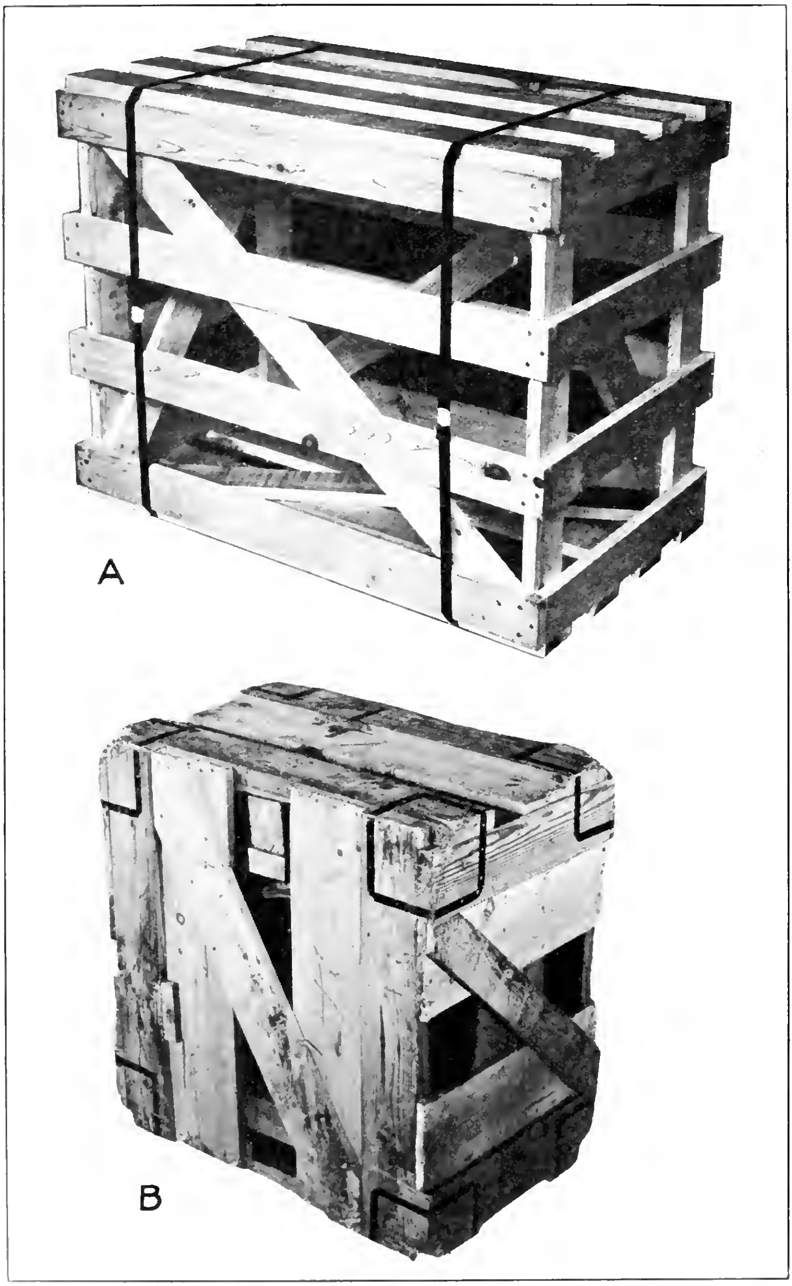
Principal styles of nailed crates are A, the 3-way corner crate and B, the box-style crate; C, a recommended method of packing a cotton gin



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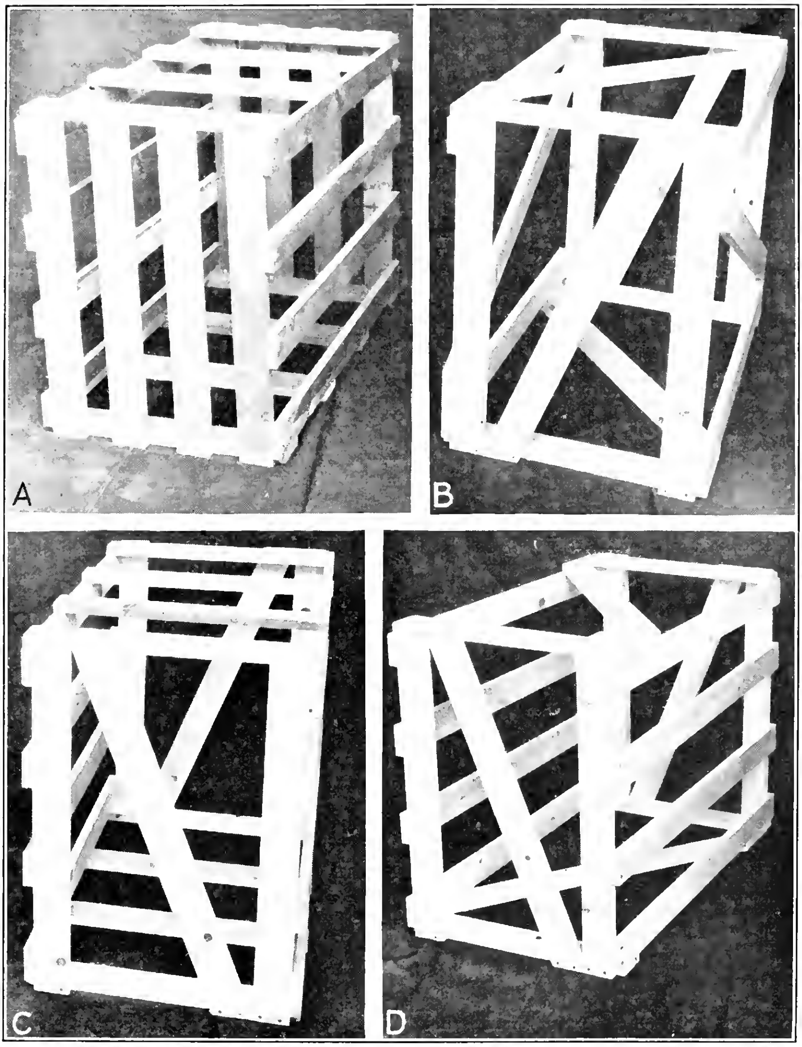
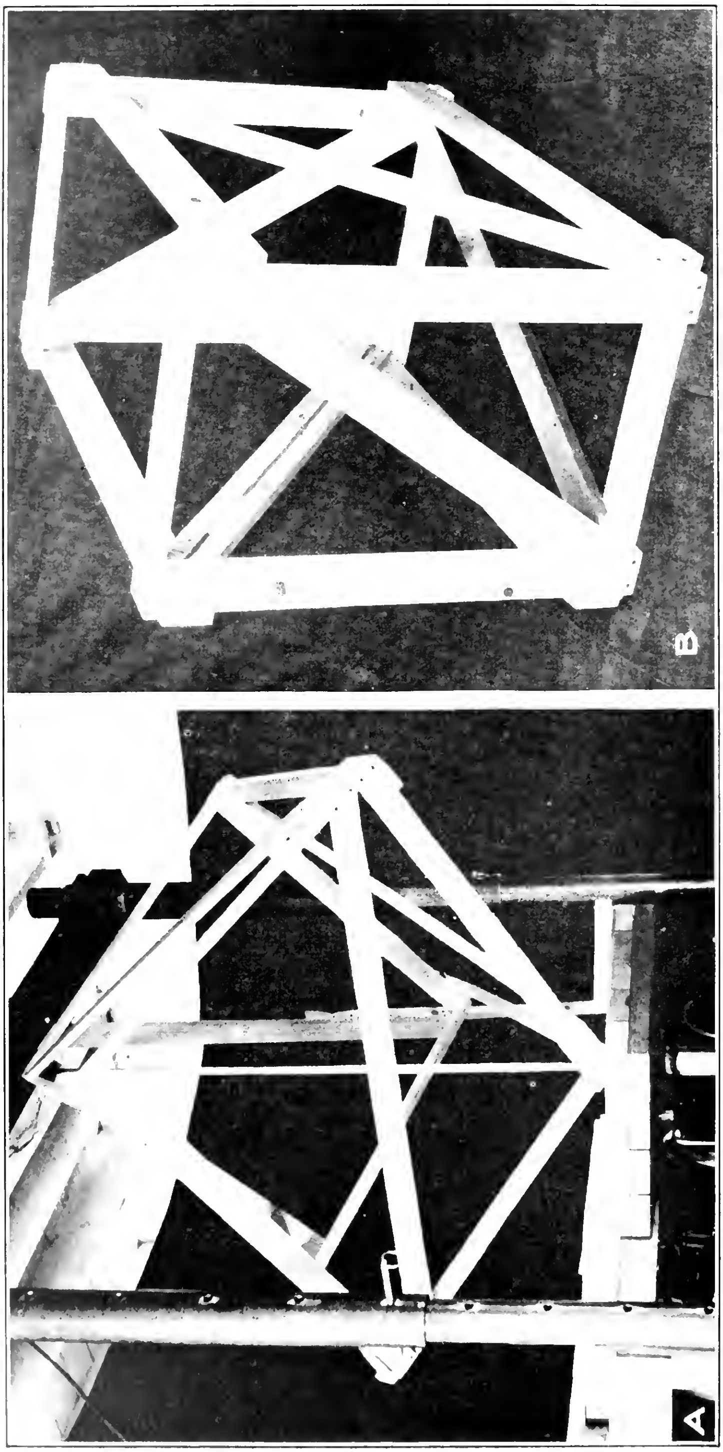
A, Box type crate reinforced with metal straps; B, method of reinforcing 3-way corner crate with metal straps



Three-way corner crates: A, Without braces; B, with six braced faces; C, with two braced faces; D, with four braced faces



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A, Crate with five braced faces, showing spiral twist when subjected to diagonally acting load; B, crate with braces nailed to wide faces of edge members from external hazards than wide members of the same cross-sectional area; therefore more sheathing is required.

Skids

The lower horizontal frame members placed lengthwise of a crate usually form the skids, which support the contents, either directly or indirectly, through intervening members. Crates carrying heavy commodities are often provided with special skids to facilitate their movement and to reinforce the bottom edge members. Skids, when supported by rollers, dollies, or slings, are sometimes subjected to severe bending stresses, in which event their strength becomes an important consideration. Skids are usually beveled at their ends to facilitate sliding or their passage on to rollers.

Sheathing

The purpose of sheathing is to protect the contents from the elements and from injury by external objects, and to reduce the pilfering or loss of small parts from the contents. Securely nailed sheathing also strengthens a crate, especially if placed diagonally. Sheathing that is placed parallel to the edge members adds rigidity to the crate as long as the joints between the boards remain tight, but the shrinkage that ordinarily occurs in the boards causes the joints to open and the sheathing to become quite ineffective as bracing. Sheathing also makes possible the use of frame constructions that otherwise would be practically useless. For example, a crate such as is shown in Plate 17, C is commonly used and gives good results only because the frame members are fastened together by the sheathing.

The sheathing may be outside the frame members and bracing or it may be inside these members.. A poorer grade of material can be used for sheathing than for other crate parts. Matched lumber is usually preferred for sheathing because it makes a tighter covering.

Defects

Knots and other defects in the edge members and braces very seriously reduce the strength of the crate, but in the sheathing, knots or knot holes having a diameter not greater than one-third the width of the piece in which they occur do not seriously reduce the serviceability of the crate except that knot holes reduce the tightness and the protection of the contents against the weather.

Moisture Content

Any decrease in the moisture content of the crate material after the crate has been built may cause loosening of the fastenings and joints, checking of the members, loosening of the internal blocking, and lessening of the effectiveness of the sheathing in preventing skewing and weaving. Crates made of lumber containing 12 to 18 per cent moisture will withstand ordinary storage conditions without any great loss in strength resulting from the shrinkage of the lumber.

Crate Corner

The corners are usually the weakest parts of any crate. An example of poor corner construction is shown in Figure 10, A. The nails holding one member are driven into end grain and therefore have comparatively low holding power. Another example of the same fault is shown in Figure 10, B. This construction may be greatly improved by lengthening the member to permit nailing into the side grain (fig. 10, C), thus forming the box-style construction. Where screws are used in place of nails, their holding power may be greatly increased if holes are bored to receive them.

The corner construction shown in Figure 10, D, is very weak, because the only nailing possible except toe-nailing is through one member into the end grain of the other two. This style of corner is frequently used in crates that are to be entirely covered with sheathing, but even then it is very weak.

The 3-way corner (fig. 10, E and F) has the advantage over other constructions in that at each corner each member is fastened by nails or bolts in two directions. If nails are used they are driven into side grain and consequently have greater holding power than if driven into end grain. If properly nailed or bolted, this style of corner has

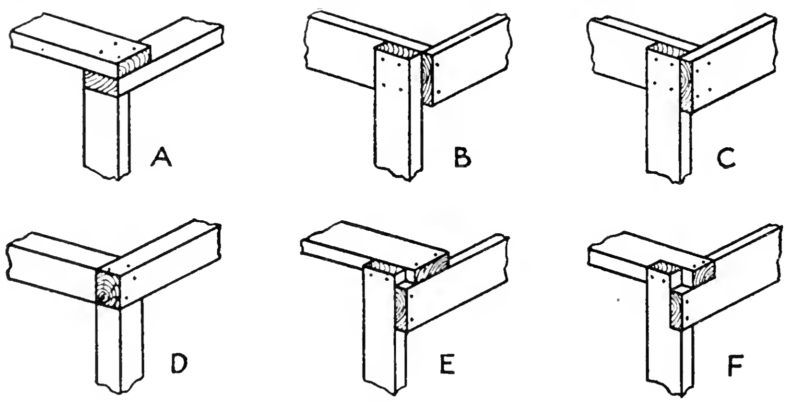


FIGURE 10.—Styles of crate corners

a considerable bracing effect. Another advantage of the 3-way corner is the arrangement of the members so that only one thickness of frame material intervenes between the contents and the outer surface of the crate, thereby minimizing the displacement.

Figure 11 shows sixteen possible arrangements of members to form a 3-way corner. A and I are the most practical unless an arrangement is desired to serve some special purpose, such as blocking the contents in position. In the box style of crate the nailing is principally into the side grain. This construction offers greater resistance than the 3-way corner to the ends being kicked out, and the sides, top, and bottom are more easily reinforced with metal bindings. (Pl. 18, A.) Without reinforcements the box-style corner is not so strong as the 3-way corner. Plate 18, B, illustrates a method of reinforcing the 3-way corner with metal straps.

BRACING

Proper arrangement of the crate members at the corners will not in itself produce a rigid crate. (Pl. 19, A.) The 3-way corner when properly fastened has considerable bracing effect, but no matter how the corners are arranged some kind of bracing across the faces is necessary to produce sufficient rigidity to resist weaving. The requirements for really effective bracing are not generally understood. Diagonal braces on six sides, as shown in Plate 19, B, produce the maximum rigidity for a minimum of material and labor. Diagonal braces on a pair of opposite faces (pl. 19, C) produce rigidity in one direction only, on two pairs of opposite faces (pl. 19, D) they produce rigidity in two directions, and on all six faces (pl. 19, B) they produce rigidity in all directions. If an odd number of faces are diagonally braced, or if two or more adjacent faces are braced and the opposite

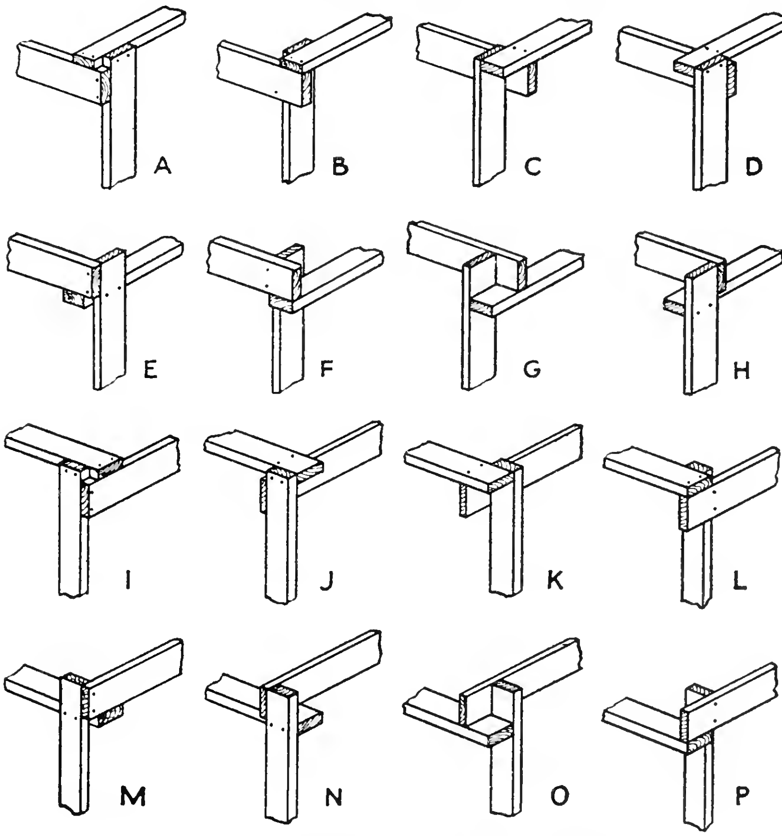


FIGURE 11.—Possible arrangements of members at a 3-way corner

faces left unbraced, the crate will twist when dropped on any of its corners. For example, if five sides of a crate are braced and the sixth is not, a drop on any corner of the crate will cause the unbraced side to distort diagonally. This action induces stresses that cause all the faces to warp, and the crate to twist. (Pl. 20, A.) If the commodity is fastened securely to any one of the crate faces, the stresses induced by twisting may cause damage to the commodity without the crate's coming in contact with it or without the crate's showing evidence of failure. If, however, the commodity is sufficiently rigid to resist diagonal distorting and twisting, and is fastened securely to the face of the crate at three or more widely separated places not in the same line, bracing may sometimes be omitted from any one side in addition to the side to which the commodity is fastened. The action of the commodity in resisting twisting greatly reduces diagonal distortion of the unbraced side.

Slight diagonal distortion in one or more of the crate faces is often desirable because the crate is better able to absorb shocks which would be transmitted to the commodity, provided the distortion does not cause the crate to touch the commodity.

Sometimes diagonal distorting and twisting only slightly rack the joints in a piece of furniture, and the damage escapes notice at the time of unpacking, but afterwards a looseness may develop which renders the commodity unsatisfactory. This looseness is usually attributed to poor workmanship or to the use of improperly seasoned lumber in manufacturing the commodity rather than to damage caused in shipment.

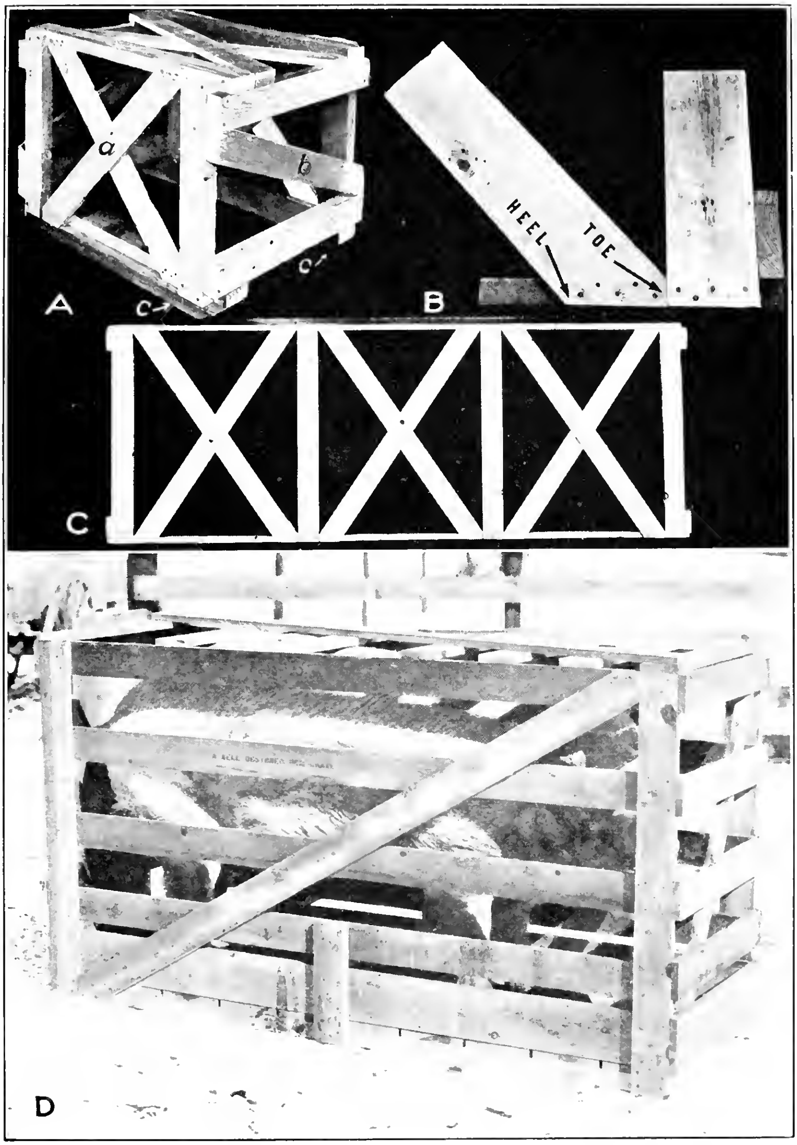
It is not always essential or even desirable therefore that all faces of a crate be diagonally braced, but great care must be exercised in omitting braces since the damage resulting to the commodity is often concealed. The number and location of the faces to be braced depend upon the character of protection that the commodity requires.

The direction of a simple diagonal wooden brace on one side of a crate with respect to those on other sides is of little consequence. Braces on opposite faces may be placed in the same or in opposite directions with equally satisfactory results because they are likely to be stressed either in tension or compression. Double or cross bracing, as shown in Plate 21, A, produces greater rigidity than a single diagonal brace on each face, but is seldom necessary unless the braces are so thin that they buckle easily when stressed in compression. Cross bracing of metal straps is quite effective when the braces are properly applied and well nailed at the corners of the crate. Braces are most effective when placed at an angle of 45° from the edge members. However, the ends of the braces should be fastened as near the corners of the crate as possible so as to avoid unnecessary bending, splitting, and other stresses in the edge members of the crate. Long crate faces should be divided into approximately square panels by cross members connecting opposite edge members (pl. 21, C), and each panel should be diagonally braced to form a truss. The crate is then not only more rigid against twisting or diagonal distortion but has greater resistance to bending.

Nails

Inability to fasten the various crate members together in such a manner that their full strength in bending, tension, and compression is developed is the chief source of crate failures. Nails are the fastenings most commonly used in crates, and much of the discussion pertaining to the factors affecting the strength of nailed joints, given on pages 11 and 12, applies also to crates.

In crate construction particular attention should be given to avoiding the direct pull of the contents on the nails; such pull would occur in the hog crate illustrated in Figure 12. The weight of the hog is carried by direct tension on the nails driven through the bottom of the crate into the lower side slats. The holding power of these nails is very good when they are freshly driven, but it decreases rapidly,



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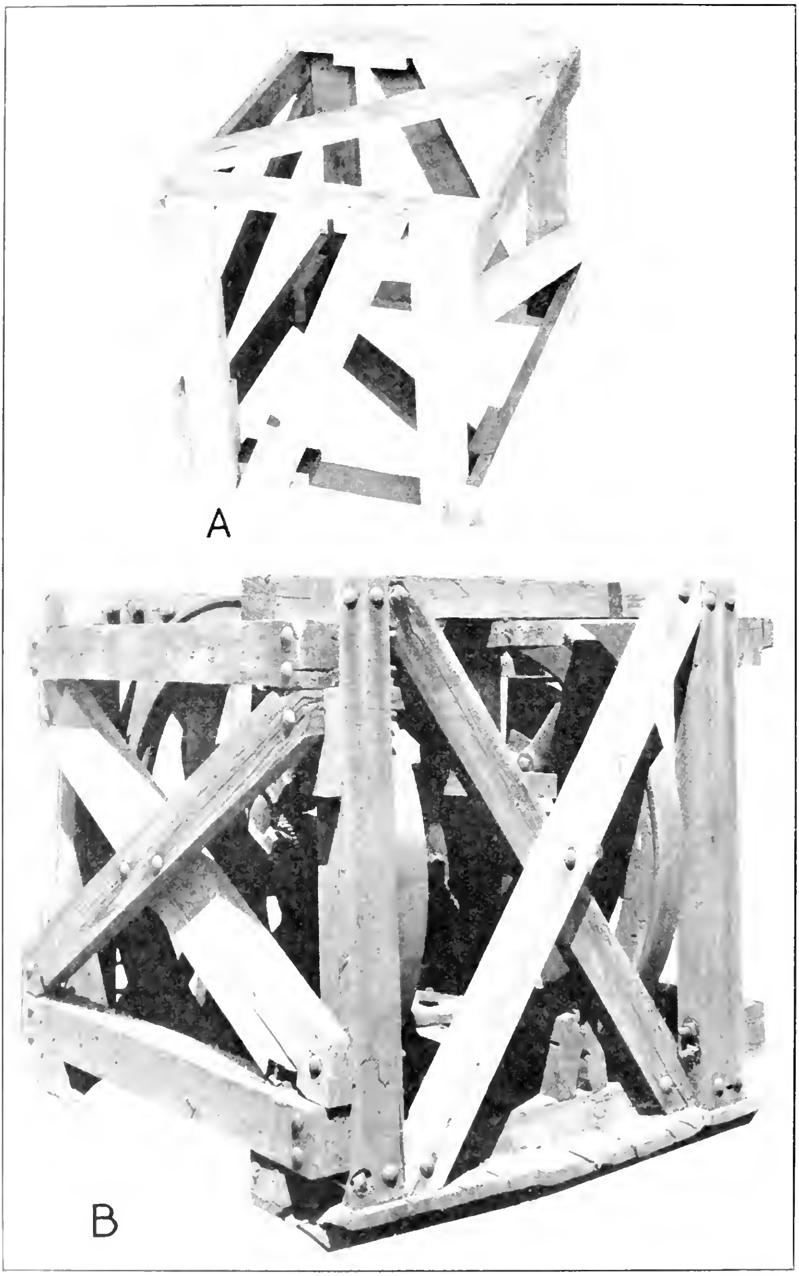
A, Three-way corner crate showing cross bracing (*a*), diagonal bracing (*b*), and extra pieces (*c*) to make stronger skids which support the vertical members and which are scarfed at the ends to facilitate sliding or the insertion of rollers; B, method of cutting and nailing a diagonal brace with proper bearing surface at the toe of the brace; C, side view of long crate showing method of increasing resistance to bending by using several sets of bracing and cross members; D, properly constructed hog crate in which the weight of the animal is carried by a floor resting on skids



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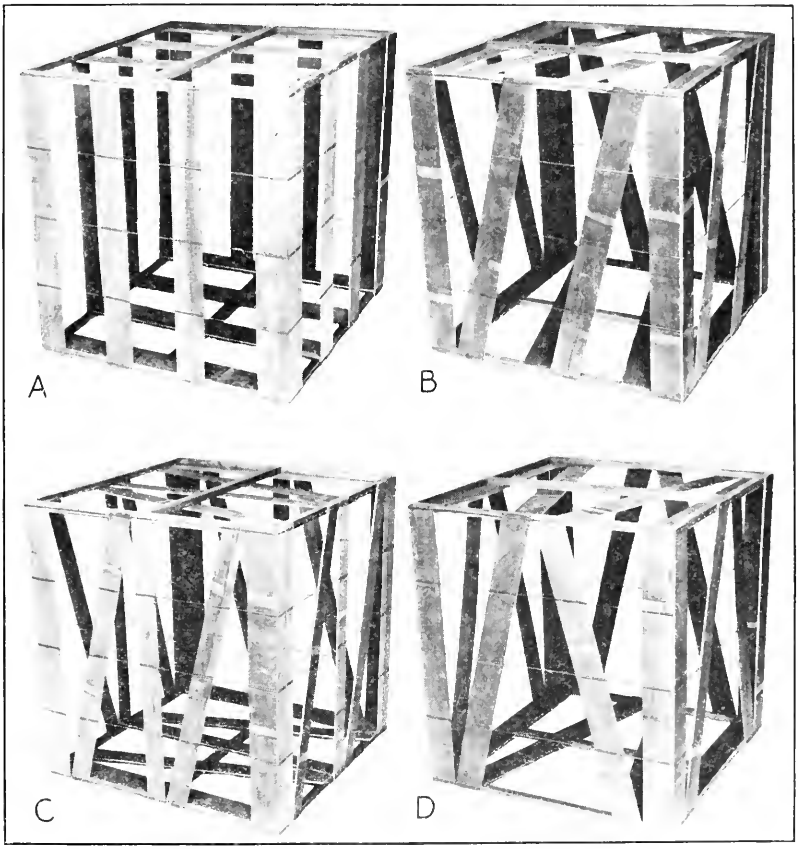
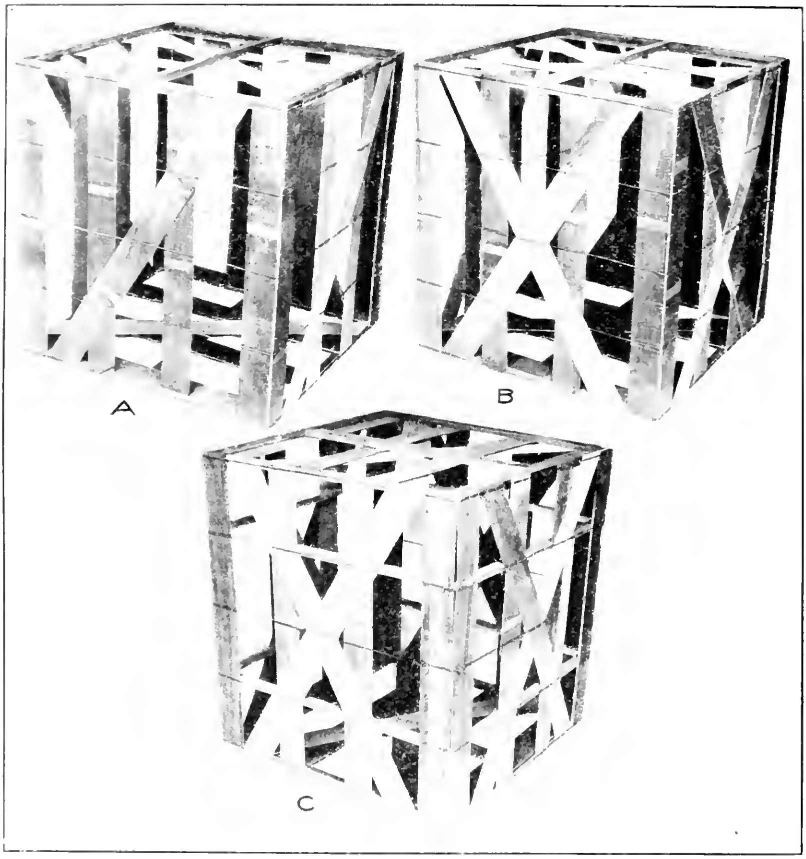
A, Crate with braces nailed to reinforcing blocks and to narrow faces of edge members; B, heavy engine crate, frame members being joined by carriage bolts



A, Wire-bound crate without diagonal braces; B, wire-bound crate with parallel diagonal braces not joined by intermediate slats; C, wire-bound crates reinforced with parallel diagonal braces joined by intermediate slats; D, wire-bound crate having each face reinforced with two diagonal braces whose ends meet at the center of an end cleat



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A, Wire-bound crate reinforced with a single diagonal brace on each face. The brace is fastened near the corners of the crate and is stapled to the wires and the slats. B, Wire-bound crate reinforced with diagonal braces crossed on each face. The braces are fastened near the corners of the crate and are stapled to the wires and the slats. C, Wire-bound crates reinforced with crossed diagonal braces and intermediate rows of cleats especially if the wood changes in moisture content after the nails have been driven. In this crate as well as in many others the direct pull on the nails may be overcome by placing the bottom boards above the lower horizontal members, as illustrated in Plate 21, D. Such horizontal members also serve as skids. In the crate illustrated in Plate 21, D, a short vertical cleat is well nailed to each skid and to its side slats. By this means the bending strength of the side slats is utilized to support the skids, which may consequently be much smaller than those which would otherwise be required. Direct pull on the nails holding the side slats is avoided by placing these slats inside the frame members. A later addition to this crate was pieces of sheet metal bent around the crate corners and clinch-nailed to reinforce the attachment of the slats at the rear end, which resist the push of the animal against the end gate. A similar use of sheet metal, to secure the ends of the center vertical blocking, is illustrated in Plate 17, C.

Cement-coated nails are preferable in crate construction to uncoated nails because of their greater holding power. A slender nail is likely to hold better than a thick nail under the repeated shocks and constant weaving action to which crates are subjected in shipment, because the slender nail bends near the surface of the pieces joined without loosening the friction grip of the nail shank. Splitting of the wood may be reduced by staggering the nails. Boring holes to receive the nails also reduces splitting and increases the nail-holding power. The diameter of such holes should be slightly less than the diameter of the nail shank. Failures due to the nails pulling out or to the splitting of the piece holding the nail points, indicate that the nails are too short.

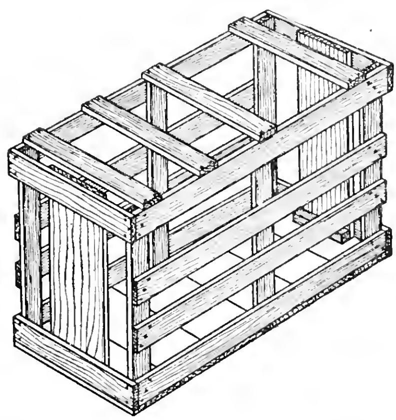


FIGURE 12.—Improperly constructed hog crate

If the ends of the diagonal braces are fitted against the edge members of adjacent faces, as illustrated in Plate 21, B, the nails fastening the brace in place can be driven closer to the crate corner. Furthermore, such construction enables a greater proportion of the shocks received in service to be transmitted to the brace directly rather than through the nails. Consequently the stress on the nails and the tendency of the edge members to split is reduced.

It is frequently an advantage in crate construction to fasten the diagonal braces to the wider face of the edge members, as shown in Plate 20, B. This practice greatly reduces the likelihood of the nails splitting the edge members, permits more nails to be used, and makes a stronger joint, especially if the nails holding the brace are clinched. Another method of reducing the likelihood of splitting and of increasing the strength of the crate is to reinforce the edge members of the crate at the end of the diagonal braces with blocks, as shown in Plate 22, A. Nailing the diagonal braces to the edge members and to the reinforcing blocks almost doubles the strength of the crate in diagonal compression.

Bolts

Bolts are especially valuable for fastening large crate members. (Pl. 22, B.) If holes which are small enough for a snug fit are bored for bolts, the crate joints are more rigid than if the bolts are loosely fitted. In the event of shrinkage or splitting of the wood, bolts may be tightened, and they will continue to be very effective, whereas nails lose much of their holding power under such conditions.

Carriage bolts are usually preferred for crate construction because their heads are oval and consequently do not require countersinking to prevent them from catching on objects. Paint applied to the bolt threads after the nuts are tightened will assist in preventing the nuts from backing off.

Screws

Lag screws and wood screws are considered poor for crate fastenings because of the great care required in drawing them down so as to make a tight joint without stripping the threads formed in the wood.

WIRE-BOUND CRATES

A wire-bound crate (pl. 23) is similar to a wire-bound box, the essential difference being that a crate has open spaces on the various faces and is sometimes reinforced with diagonal braces. Wire-bound crates have the same general characteristics as wire-bound boxes, but unless braced they are less resistant to diagonal distortion and weaving.

DETAILS OF CONSTRUCTION

Stapling

It is very desirable to fasten each slat of a wire-bound crate with at least two staples astride each binding wire; otherwise the slats and wires pivot about the point of stapling and offer but little resistance to the weaving of the crate. The staples are most effective in preventing weaving if placed near the edges of the slats because of the greater leverage thus afforded the staples, as each one of a pair resists pressure from a direction opposite to that of the pressure acting on the other.

Diagonal Braces

No matter how well the crate is stapled, the proper arrangement of diagonal braces greatly increases the resistance to weaving. The braces are most effective if placed at an angle of about 45° to the edges and if their ends are fastened near corners of the crate.

If two diagonal braces are placed parallel on the face of the crate with one end of each respective brace fastened near the center of one of two parallel end cleats (pl. 23, B), the rigidity of the crate is but slightly greater than if the slats or braces are parallel with the edges of the crate. (Pl. 23, A.) If intermediate slats are used with the braces to form a truss, as shown in Plate 23, C, or if the braces run at an acute angle with each other, their adjoining ends being fastened near the center of the same end cleat, as shown in Plate 23, D, the rigidity of the crate is much greater than that of crates without braces or that of the crates with braces and without intermediate slats to complete the truss. The types of bracing shown in Plates 23, C and D, add approximately the same amount of rigidity (fig. 13) to the crate as single diagonal braces fastened near the corners of the crate. (Pl. 24, A.) The rigidity of the crate may be further increased by stapling the braces to the wires and intermediate slats so as to support the braces against bending when stressed in compression. Maximum crate rigidity for a minimum of material is obtained, however, by using crossed diagonals on each face, as shown in Plate 24, B. If crossed diagonals are used on each face, one diagonal of each pair is always in a position to act in tension. If their ends are fastened securely, diagonal braces of thin material such as is commonly used in wire-bound construction are much more effective acting in tension than in compression.

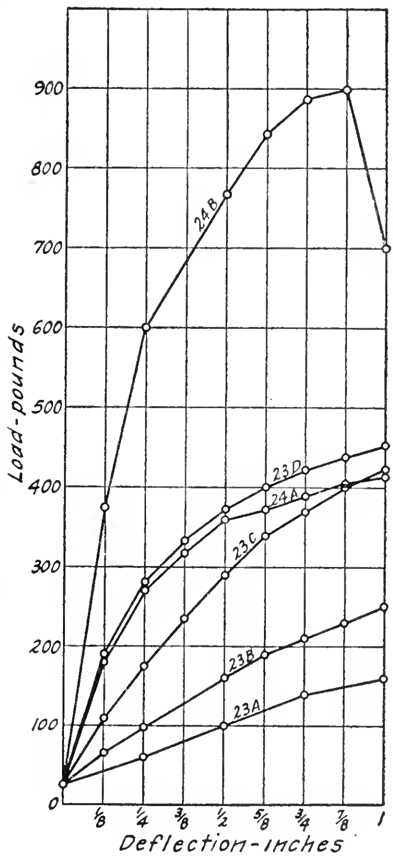


Figure 13.—Effect of different systems of bracing on resistance of wire-bound crates to diagonal distortion. The curves correspond to the bracing systems illustrated in the plates of like designation. The crate is loaded, as shown in Plate 20, A

Intermediate Cleats

Intermediate rows of cleats (pl. 24, C) and styles A and D end battens (fig. 7) are commonly used to reinforce the slats and braces and to support the weight of the crate contents either directly or indirectly through supporting blocks which may be added. These cleats and battens also support the slats and braces against bending and breaking across the grain, thereby increasing the rigidity of the crate and permitting the use of thin lumber.

Ends

Various types of end construction are used for wire-bound crates. The ends are sometimes made of slats having the same width and thickness as the slats in the crate sides, top, and bottom, and in other instances they are made of thicker lumber. These slats are sometimes fastened to the inside and sometimes to the outside of the end cleats. Where the crate ends are made of thin slats they are sometimes reinforced with the various arrangements of battens shown in Figure 7. The type of end required for a wire-bound crate and whether it should be fastened inside or outside the cleats will depend upon the nature of the contents and the manner in which it is supported in the crate.

INTERNAL PACKING AND CAR LOADING

There are definite principles for packing commodities in containers just as there are definite principles for the design of the containers. Packing and container design are so interrelated that observance of correct principles in container design will not compensate for faulty packing, or conversely. In fact, for best results the design of the container and the design of the packing should go together, being considered as a single job.

Shocks to goods in transportation, such as those caused by the weaving, swaying, and rolling of transporting vehicles, and heavy static or quiescent loads sometimes supported by the packages in the bottom layer of cargo are inevitable, although by care they can be reduced.

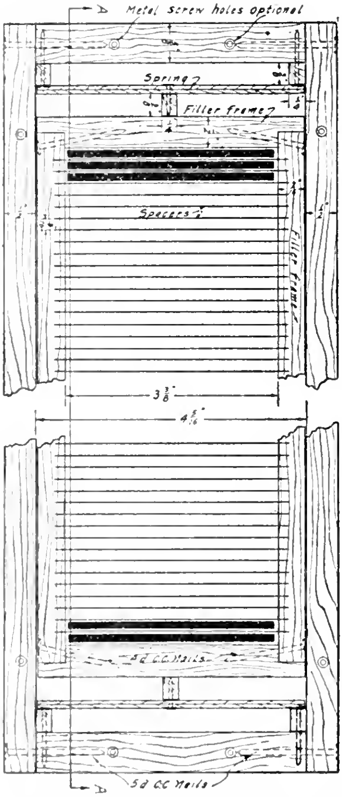


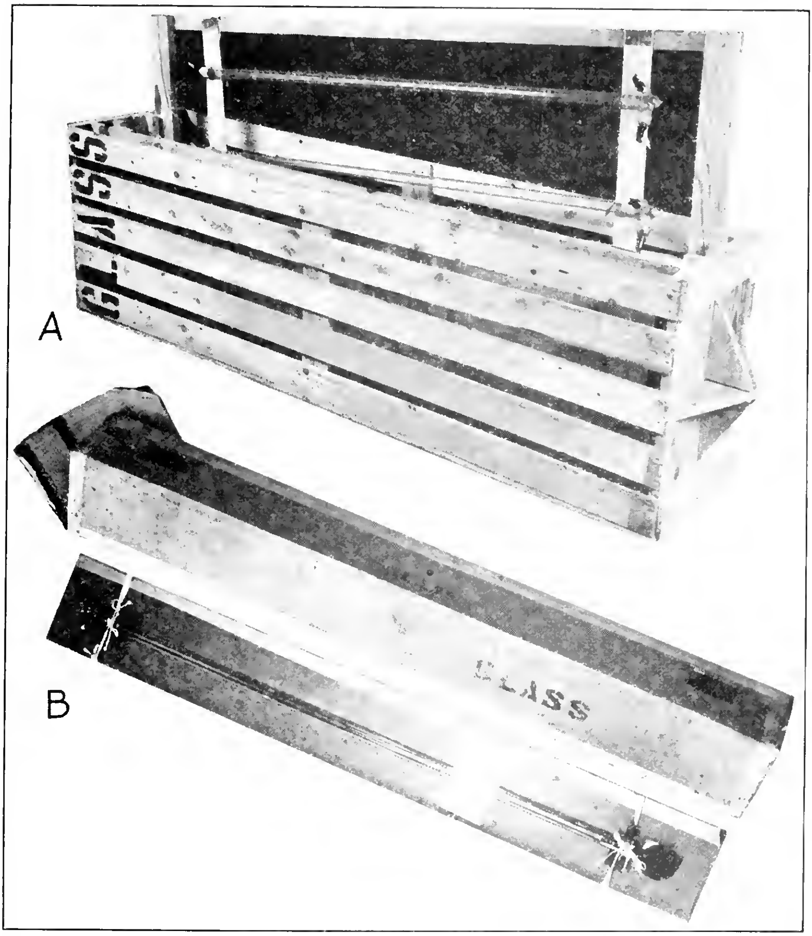
FIGURE 14.—Top view (open) of suggested box for lantern slides, illustrating the use of wooden springs for absorbing shock

In general, the container and packing should be so designed as either to absorb the shocks and relieve the forces by means of cushioning materials, or to distribute, localize, or transform the forces in such a manner that the commodity and container will be able to withstand them without damage.

Protection against shock is essentially the problem of bringing to rest a body that is in motion. This action involves two factors: (1) The force exerted and (2) the distance through which this force acts. Thus, if considerable distance is available for stopping a moving body it can be brought to rest by a small force, while if it must be stopped in a short distance a large force must be applied. This fact is illustrated by the use of thick pads of soft materials for packing very delicate articles and the use of comparatively thin pads of more rigid materials for packing articles that can withstand greater stresses. In the first case, the shock is absorbed by a small force acting through a long distance; in the second, a large force acts through a short distance.

One of the chief purposes of packing materials, such as excelsior, corrugated pads, and springs, is to decrease the magnitude of the force required to stop motion by increasing the distance through which it can act. Figure 14 illustrates the use of thin pieces of wood to absorb shock.

Fragile commodities shipped in heavy, rigid containers require greater spring in packing materials than when light flexible containers are used. This is because the rigid container transmits practically all the shocks to the packing materials, whereas the flexible container



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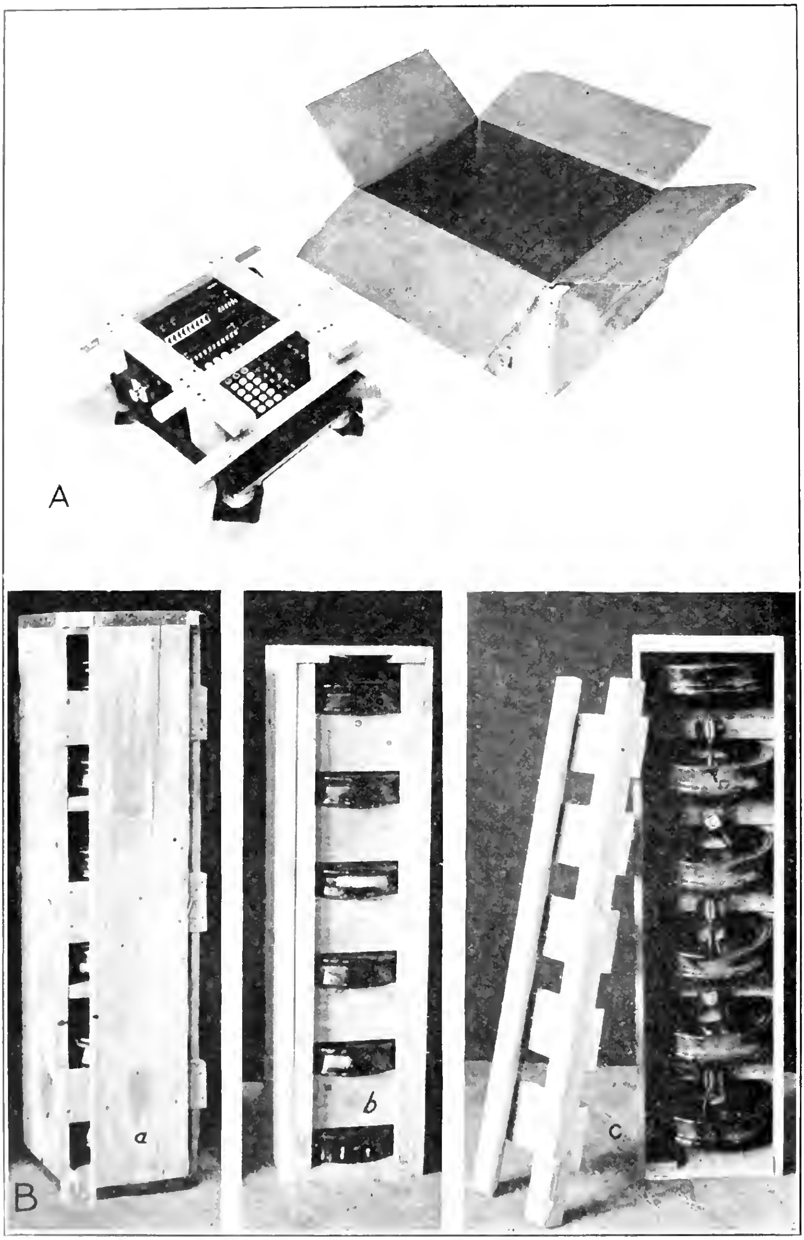
Application of psychology to packing delicate articles: A, Method of packing mercury-vapor lamp tubes in a lightweight open crate; B, method of packing a mercury-vapor lamp tube in corrugated fiber box. Holes have been cut in the side of the box to expose the contents to view



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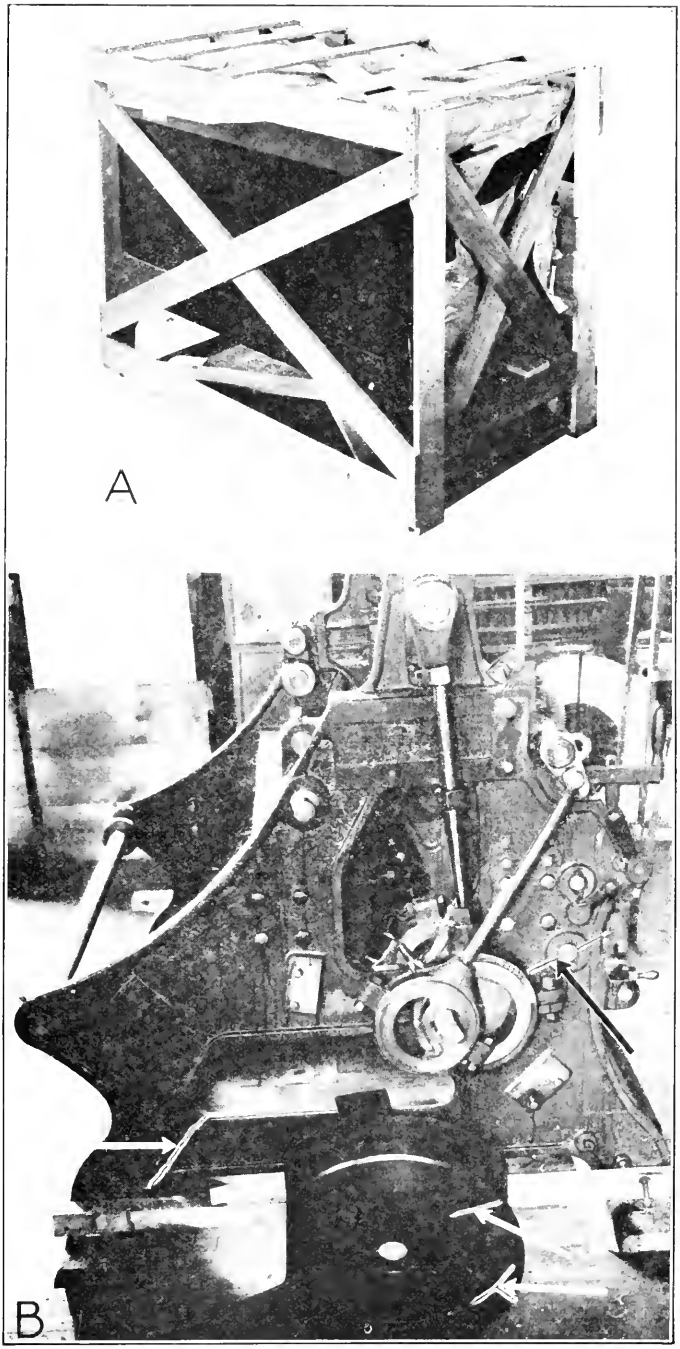
A, A method of localizing the stresses of transportation at the parts of the commodity best able to withstand them. B, containers for high-voltage porcelain insulators. Original (a) and improved (b) and (c)



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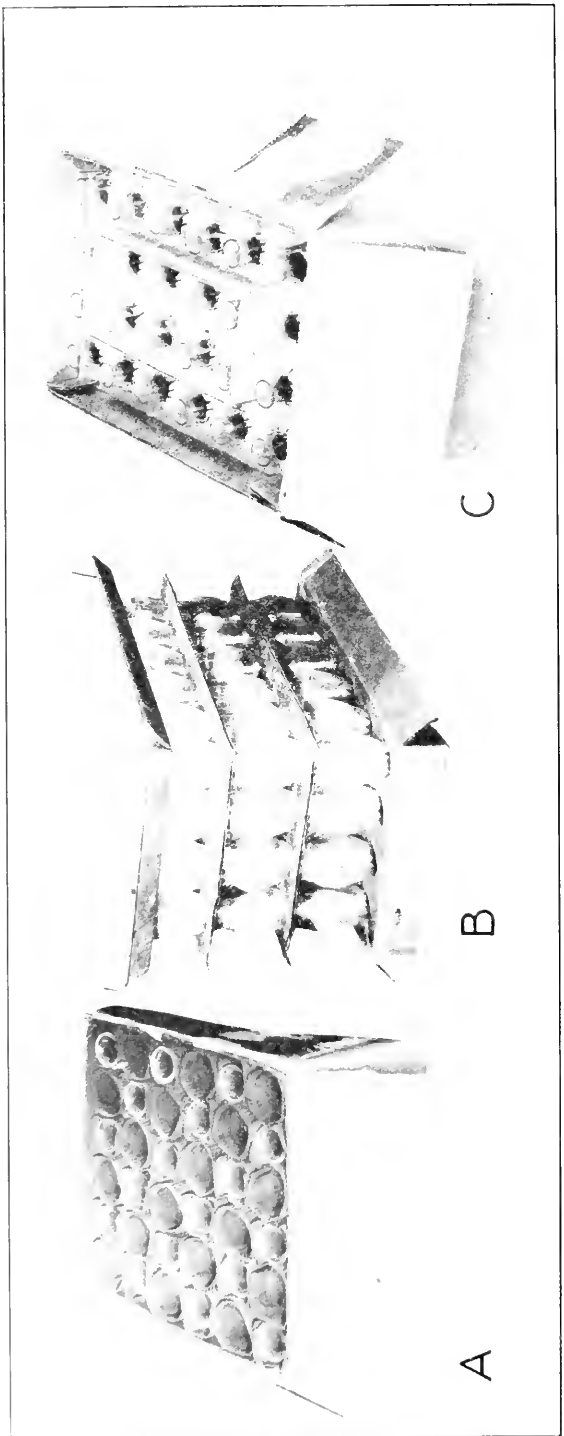
A, Rear view of a crate for a dresser; B, wire-bound box machine damaged in transit



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Methods of packing lamp chimneys: A, Poor method; B, improved arrangement of chimneys in pad; C, open bottom of loaded box dissipates the shocks by springing and by distorting its own parts. Also the light flexible container and packing has a psychological effect on the persons handling freight. The application of psychology to packing delicate articles such as X-ray tubes and mercury-vapor lamp tubes (*29*) is illustrated in Plate 25, A, and B, where the articles are exposed to view in a very light and flimsy-appearing open crate or in a corrugated box having holes cut in its sides. In some instances the container is provided with grips to facilitate handling and may also be equipped with shoes or other devices to keep it in an upright position.

Plate 26, B, illustrates some principles of absorbing and distributing shocks that would otherwise damage the commodity. The commodity is a porcelain electric insulator. If it is placed in a box without packing materials or if packed as illustrated in Plate 26, B, *a*, the impact when the box strikes flatwise is concentrated at a single point on each unit of the insulator, and breakage results. By fitting the box with two ladderlike frames (pl. 26, B, *b* and *c*) that support the insulators free from the sides of the container the shocks incident to the package dropping flatwise are transmitted to two points on each unit instead of to a single point. Furthermore, when the package strikes on its side the insulators wedge themselves between the rails and spring them apart. This wedging action and springing of the ladder, combined with crushing of the wood at the two points of support, reduces the shock that would otherwise be transmitted to the contents.

The practice of binding a number of barrels, or rolls of newsprint, together, and allowing them to slide as a unit on the car floor illustrates a method of absorbing shocks as applied to car loading. In this method part of the shock is absorbed by the individual units tipping partly over and in so doing rubbing against other units, and part by the friction of the entire mass sliding on the car floor. This principle of absorbing shock is also used in binding together several tons of sheet iron. In this instance, part of the shock is absorbed by the individual units sliding one on the other, and part is absorbed by the load sliding on the car floor.

Plate 17, C, is an example of transforming and distributing the stresses of transportation rather than absorbing them by cushioning materials. The crate illustrated is an exceptionally strong container for export shipment of machinery; yet, previous to the adoption of the methods shown, much damage occurred to the contents because of faulty packing. The crate was built with heavy frame members securely reinforced with 2 by 4 inch diagonal braces and crossties and was sheathed with ⅞-inch tongue-and-grooved lumber. All joints were securely nailed, and the container was well strapped. The machine within the crate is a cotton gin. Its ends are cast iron and carry two large full-length shafts with heavy, rigidly attached parts. The other parts of the gin are mostly wood. The original method of packing consisted in bolting the skids of the machine securely to the crate and blocking between the machine and the ends and sides of the crate. The top of the crate was tight against the machine. As may be readily seen, the original method required a crate that would withstand the hazards of transportation with practically no distortion, because any distortion would transmit the shocks of transportation directly to the machine or would allow the crate to skew away from the ends of the heavy shafts and thus permit the entire end thrust of the shafts to come on the ends of the machine, giving rise to severe bending stresses in the cast iron.

It is impossible to build a crate that is as rigid as cast iron, because wood itself is somewhat yielding and there is always some looseness at nailed joints. Consequently, when the corner of this crate struck a heavy, rigid object both the crate and the gin were skewed diagonally—necessarily so because the two were securely bolted and blocked together. Such distortion was sufficient to twist the ends of the machine and break the cast-iron legs. Again, if the crate were dropped on the top or bottom edge of the end, the machine would be distorted lengthwise, and failures would likely occur in the end casting where the shafts were fastened; also the weight of the shafts would tend to spring the end of the crate and allow a large portion of the end thrust of the shafts to come on the castings. This end thrust was sufficient in itself to cause failures in the end castings without any twisting. The machine is amply strong to withstand drops flatwise on the sides, top, or bottom or on the edges of these faces.

Overcoming the difficulty, obviously, was not a problem of building a more rigid crate but of blocking the machine so that the crate could distort slightly and absorb the shocks of transportation without transmitting them to the cast-iron ends in the form of severe bending or torsional moments. In the improved method of packing, the bolts fastening the machine to the crate were omitted, and each end of the machine was blocked with two 4 by 8 inch timbers placed at right angles to each other. The horizontal timber was placed across the end of the machine about midway between top and bottom and was fitted against the machine at several points, including the shaft bearings, which thus prevented the shaft from moving endwise. The horizontal timber was not fastened to the crate. The vertical timber was placed about in line with the center of gravity of the machine and was fastened securely to the top and bottom of the crate by sheet-metal angles. The purpose of this timber was to prevent the machine from moving endwise and to act as a pivoting block. The crate could distort without skewing the machine. The original blocking was used on the sides and top. This arrangement of the blocking allowed the end thrust to be distributed to the parts of the machine best suited to withstand it. The crate itself absorbed the diagonal stresses which formerly introduced skewing in the machine. The machine was thus required to withstand only the direct load and end thrust at points in such a manner that little bending and torsion were induced.

Plate 26, A, illustrates a method of localizing the stresses of transportation at the parts of the commodity best able to withstand them. The commodity packed is a calculating machine with the operating motor built in. The outer shipping container is a nailed box having single-piece ends and sides and wide boards in the top and bottom. This construction is used to protect the machine against diagonal distortion stresses. The outer box is fitted on the inside with a corrugated box which acts as a cushion to absorb shock. The machine when placed in the box is set on felt pads, which provide further cushioning against shocks. Blocks of wood are fastened against the base of the machine to prevent movement endwise or sidewise. A wood framework is built up and fitted between the box and the top of the machine at points best able to withstand stresses. A felt pad, not shown in the illustration, is placed over the top of this framework to assist the corrugated box in absorbing shocks.

The principle of transforming and distributing stresses is also applied in the packing of dressers, as illustrated in Plate 27, A. Here the dresser is supported so that the weight is not carried by the legs or other easily broken parts. The corners and edges of the dresser do not come in direct contact with the crate except on the one face that is fastened to the crate, and the dresser is fastened at only two points. The crate can undergo considerable diagonal distortion without coming in contact with the dresser and without introducing diagonal distortion stresses that tend to rack the joints in the furniture.

Plate 27, B, illustrates the kind of damage that sometimes results from not supporting the heavy parts of commodities so as to prevent their inertia from causing damage to the lighter parts. The machine was bolted to heavy skids and was amply covered to protect it from objects. It was loaded lengthwise of the car, and the skids were blocked to prevent sliding. The white lines mark the breaks that resulted from the apparent inability of the castings to withstand the large inertia of the top of the machine when the car received an abnormally heavy bump in switching. This unusual damage could have been prevented if the top had been braced diagonally to the far ends of the skids, or if the machine had been loaded crosswise of the car.

Another illustration of internal packing appears in Plate 28. A method of packing lamp chimneys that resulted in considerable breakage is shown in Plate 28, A. The chimneys were covered with individual corrugated-strawboard wraps and were packed in a double-faced corrugated box. The breakage was caused by the upper rows of chimneys crashing down upon the lower ones when the box was dropped flat on the end or side. Increasing the depth of the corrugations in the individual wraps and using boxes of double thickness and pads of various kinds reduced the breakage only slightly. Since the wraps offered very little resistance to collapse, such methods of packing did not materially reduce the amount of pressure exerted on the bottom layer of chimneys.

Suspending each individual chimney in die-cut pads made of double-faced corrugated fiber board, as shown in Plate 28, B and C, prevented practically all breakage. By this means each chimney is required to carry only its own weight and is so spaced that it does not come in contact with other chimneys or with the sides of the shipping container.

In packing goods for export, consideration should be given not only to the adequacy of the packing to protect the merchandise against loss or damage in transit but also to its effect on the transportation charges and the amount of duty that will be imposed upon the package at its destination. Ocean-transportation charges are based on both volume and weight of the package, and there are supercharges for single packages exceeding certain weights and over-all dimensions. Sometimes the shipping costs may be greatly reduced by dismantling parts so as to reduce the size of the shipping containers. The savings thus made should of course be balanced against the cost of dismantling and the cost of assembling at destination. Complete information on the regulations in force in different countries with regard to assessment of duty on merchandise may be obtained upon request from the United States Department of Commerce, Bureau of Foreign and Domestic Commerce.

APPENDIXES

The purpose of the Appendixes A to H is to give specific information necessary in the application of the principles of the design and construction of shipping containers. They contain information on the properties of container woods and instructions as to their conditioning, formulas for design, descriptions of methods of testing, specifications, and statistics.

APPENDIX A. CHARACTERISTICS AND BEHAVIOR OF CONTAINER MATERIALS

The following are the principal requisites of container materials: Low cost, availability, lightness, ability to take fastenings and hold them securely, and resistance to breaking, splitting, buckling, and puncturing. With food containers it is important that the material should not impart taste or odor to the contents. The capacity to display lettering well and to stay in place is also important. Capacity to stay in place is most important when either the material or the container is to remain in storage for a long period of time or is to be exposed to severe changes of moisture or atmospheric conditions.

NAILING OF WOOD

NAIL-HOLDING POWER

The maximum of resistance to be overcome in withdrawing nails from wood by pulling along the nail shank is known as the nail-holding power. It depends on the friction between the nail shank and the wood fibers, and varies for ordinary sizes of nails with the density of the wood, the direction of the shank relative to the grain of the wood, the form of the point, the character of the shank, the diameter of the nail, the depth of penetration, the moisture content of the wood, and changes in moisture content after the nails are driven.

For clear, sound wood the nail-holding power varies with the density in the manner indicated in Figure 15 and almost directly with the depth of penetration (Table 1) and diameter of nail. (Table 2.) In other words, the nail-holding power depends upon the amount of wood substance in contact with the nail. It is therefore evident that checks, splits, and rot very seriously reduce the nail-holding power. Table 3 indicates that the work or energy required to pull nails also varies with their size and with the density of the wood.

TABLE 1.—*Resistance to withdrawal of twelvepenny cement-coated nails driven to different depths into side grain of air-dry western yellow pine*

Depth driven	Tests	Force required to start withdrawal	Depth driven	Tests	Force required to start withdrawal
	Number	*Pounds weight*		*Number*	*Pounds weight*
½ inch	44	70	1¼ inches	42	216
1 inch	44	156	1½ inches	44	268
1⅛ inches	88	195	1¾ inches	42	311

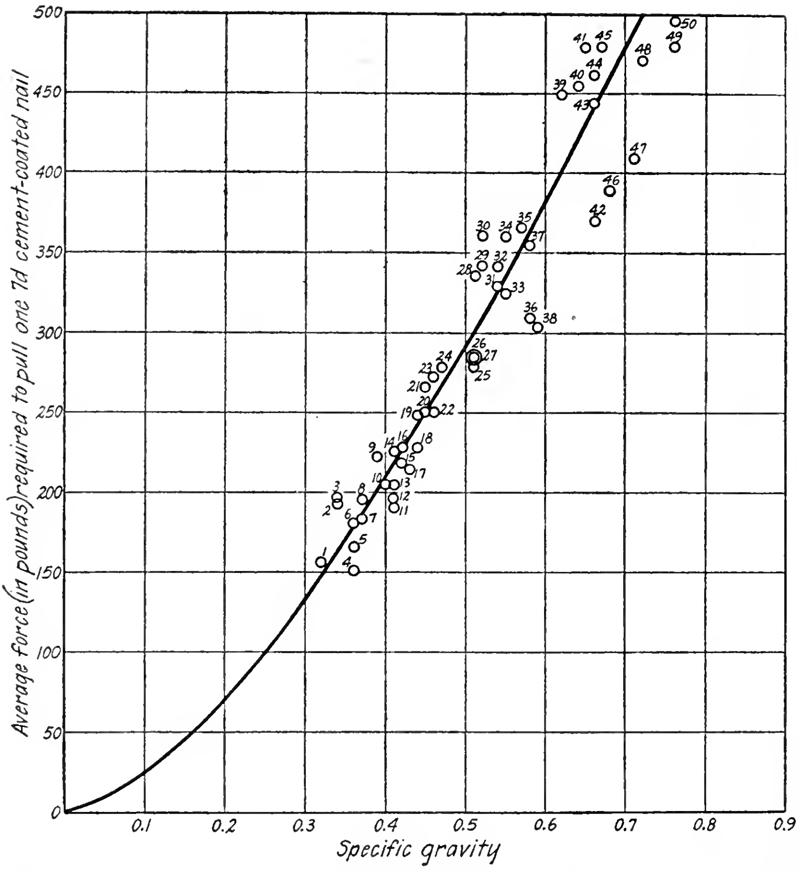


FIGURE 15.—Relation of specific gravity of wood to nail-holding power; sevenpenny cement-coated nails driven 1¼ inches into side grain and pulled at once

KEY TO SPECIES

1. Cedar, northern, white.
2. Cottonwood, eastern.
3. Cedar, western red.
4. Aspen.
5. Fir, lowland white.
6. Spruce, Engelmann.
7. Fir, California red.
8. Cottonwood, black.
9. Pine, northern white.
10. Fir, silver.
11. Fir, white.
12. Basswood.
13. Aspen, largetooth.
14. Spruce, red.
15. Poplar, yellow.
16. Hemlock, eastern.
17. Spruce, white.
18. Pine, western yellow.
19. Pine, lodgepole.
20. Pine, western white.
21. Chestnut.
22. Pine, jack.
23. Hemlock, western.
24. Cypress, southern.
25. Pine, Norway.
26. Douglar fir.
27. Gum, red.
28. Maple, silver.
29. Magnolia, cucumber.
30. Gum, tupelo.
31. Pine, pitch.
32. Elm, American.
33. Pine, mountain.
34. Sycamore.
35. Pine, pond.
36. Larch, western.
37. Pine, shortleaf.
38. Pine, loblolly.
39. Maple, black.
40. Ash, white.
41. Maple, sugar.
42. Pine, longleaf.
43. Oak, red.
44. Birch, red.
45. Beech.
46. Pine, slash.
47. Locust, black.
48. Oak, white.
49. Locust, honey.
50. Hop-hornbeam.

TABLE 2.—*Resistance to withdrawal of cement-coated nails of different diameters driven to 1⅛-inch depth into side grain of air-dry western yellow pine*

Size of nail			Force required to start withdrawal [2]
Penny	Gauge number [1]	Diameter in inch	
			Pounds weight
6	13	0.0915	140
10	11	.1205	167
12	10	.1350	183
16	9	.1483	214

[1] Steel wire gauge (Washburn & Moen). [2] Each value represents tests on 80 nails.

TABLE 3.—*Work required to pull from dry wood different sized nails which were driven into side grain*

Size of nail	White pine		Douglas fir		Yellow birch	
	Tests	Work of pulling per inch withdrawn	Tests	Work of pulling per inch withdrawn	Tests	Work of pulling per inch withdrawn
	Number	*Inch-pounds*	*Number*	*Inch-pounds*	*Number*	*Inch-pounds*
Fourpenny	12	59	30	66	12	72
Sixpenny			20	65		
Eightpenny	12	84	29	152	12	110
Tenpenny			20	183		
Twentypenny	12	170	30	295	11	427
Sixtypenny	12	192	30	326	12	389

DIRECTION OF NAIL SHANK

The resistance to withdrawal is greater if the nails are driven into side grain than if driven into end grain. (Table 4.) It may be observed that the difference between the resistance to withdrawal of nails from the end surface and from the side grain, which is the average of the radial and tangential surfaces, is greater for the lightweight woods, which are designated under Groups 1 and 2, than for heavier woods, which are designated under Groups 3 and 4. There is, however, no important difference in the resistance to be overcome in pulling nails from radial (edge-grain) and tangential (flat-grain) surfaces.

TABLE 4.—*Nail-holding power of various species of wood*

[Sevenpenny cement-coated nails driven to a depth of 1¼ inches and pulled at once]

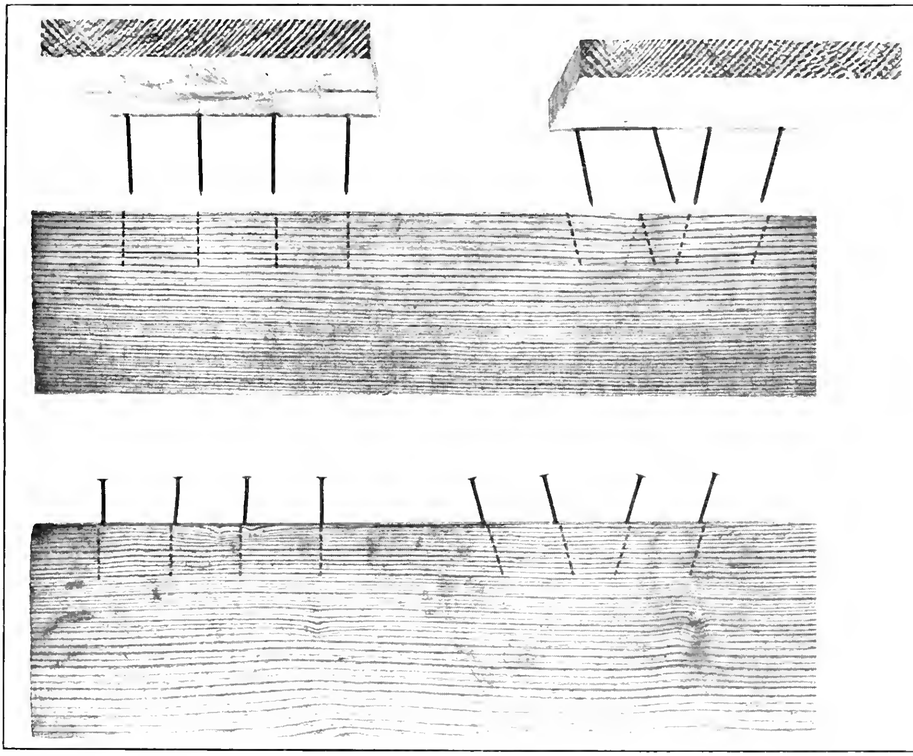
Group and species [1]	Source of test material	Trees	Moisture content at test	Specific gravity oven-dry based on volume when oven-dry	Holding power of nails driven into—		
					End surface	Radial surface	Tangential surface
GROUP 1		*Number*	*Per cent*		*Pounds weight*	*Pounds weight*	*Pounds weight*
Aspen	Colorado		4.3	0.36	93	145	157
Aspen, largetooth	Wisconsin	5	6.5	.41	157	202	207
Basswood	Pennsylvania	5	6.5	.41	138	199	194
Cedar, northern white	Wisconsin	5	9.3	.32	103	153	160
Cedar, western red	Montana	10	7.6	.34	118	192	202
Do	Washington						
Chestnut	Maryland	10	9.2	.45	172	258	273
Do	Tennessee						

[1] Data are not available on all species in each group.

TABLE 4.—*Nail-holding power of various species of wood*—Continued

Group and species [1]	Source of test material	Trees	Moisture content at test	Specific gravity oven-dry based on volume when oven-dry	Holding power of nails driven into—		
					End surface	Radial surface	Tangential surface
GROUP 1—continued		*Number*	*Per cent*		*Pounds weight*	*Pounds weight*	*Pounds weight*
Cottonwood, black	Washington	5	5.9	0.37	122	194	196
Cottonwood, eastern			6.8	.34	143	189	197
Cypress, southern	Louisiana	10	8.3	.47	144	266	291
Do	Missouri						
Fir, California red	California	3	9.0	.37	100	177	189
Fir, lowland white	Idaho	5	5.3	.36	60	150	182
Fir, silver	Washington	5	4.9	.40	86	201	207
Fir, white	California	8	8.0	.41	104	176	203
Magnolia, cucumber	Tennessee	5	5.1	.52	233	350	335
Pine, jack	Wisconsin	5	7.6	.46	161	228	272
Pine, lodgepole	Colorado	8	6.3	.44	141	244	252
Do	Idaho						
Pine, northern white	Wisconsin	5	7.7	.39	136	220	225
Pine, Norway	do	5	7.4	.51	165	273	282
Pine, western white	Montana	5	8.2	.45	134	255	246
Pine, western yellow	California	7	6.6	.44	122	224	233
Do	Oregon						
Poplar, yellow	Tennessee	5	7.3	.42	162	212	223
Spruce, Engelmann	Colorado	5	9.4	.36	136	177	184
Spruce, red	Tennessee	5	10.7	.41	148	229	221
Spruce, white	Wisconsin	5	7.6	.43	146	209	218
GROUP 2							
Fir, Douglas	Oregon	28	6.3	.51	183	273	296
Do	Washington						
Hemlock, eastern	Tennessee	28	8.9	.42	127	225	230
Do	Wisconsin						
Hemlock, western	Washington	9	6.7	.46	149	266	277
Larch, western	Idaho	5	4.4	.58	180	299	319
Pine, loblolly	Florida	10	8.0	.59	179	271	335
Pine, longleaf	do	34	7.7	.64	244	362	376
Do	Louisiana						
Do	Mississippi						
Pine, mountain	Tennessee	5	7.1	.55	209	318	330
Pine, pitch	do	5	7.7	.54	235	325	330
Pine, pond	Florida	5	7.5	.57	211	348	384
Pine, shortleaf	Louisiana	6	7.2	.58	235	331	377
Pine, slash	Florida	5	7.6	.68	290	356	420
GROUP 3							
Elm, American	Pennsylvania	5	8.2	.54	236	344	339
Gum, red	Arkansas		8.3	.51	192	292	278
Gum, tupelo	Louisiana	6	9.3	.52	233	376	345
Do	Missouri						
Maple, silver	Wisconsin	5	6.8	.51	280	333	338
Sycamore	Tennessee	5	7.0	.55	270	369	349
GROUP 4							
Ash, white	Arkansas	5	8.9	.64	385	455	452
Beech	Indiana	5	8.4	.67	358	495	460
Birch, yellow	Wisconsin	5	8.6	.66	331	473	451
Hop-hornbeam	do	3	6.5	.76	457	513	480
Locust, black	Tennessee	3	4.1	.71	404	461	345
Locust, honey	Indiana	1	6.5	.76	431	508	449
Maple, black	do	1	9.8	.62	357	480	415
Maple, sugar	do	4	9.2	.65	396	497	459
Oak, red	Arkansas	22	8.4	.66	312	466	422
Do	Tennessee						
Do	New Hampshire						
Oak, white	Arkansas	10	8.6	.72	320	496	444
Do	Louisiana						

Nails driven either at an angle of 90° to the surface or driven at an angle somewhat less than 90°, as shown in Plate 29, have approximately the same holding power when pulled in a direction perpendicular to the surface of the board



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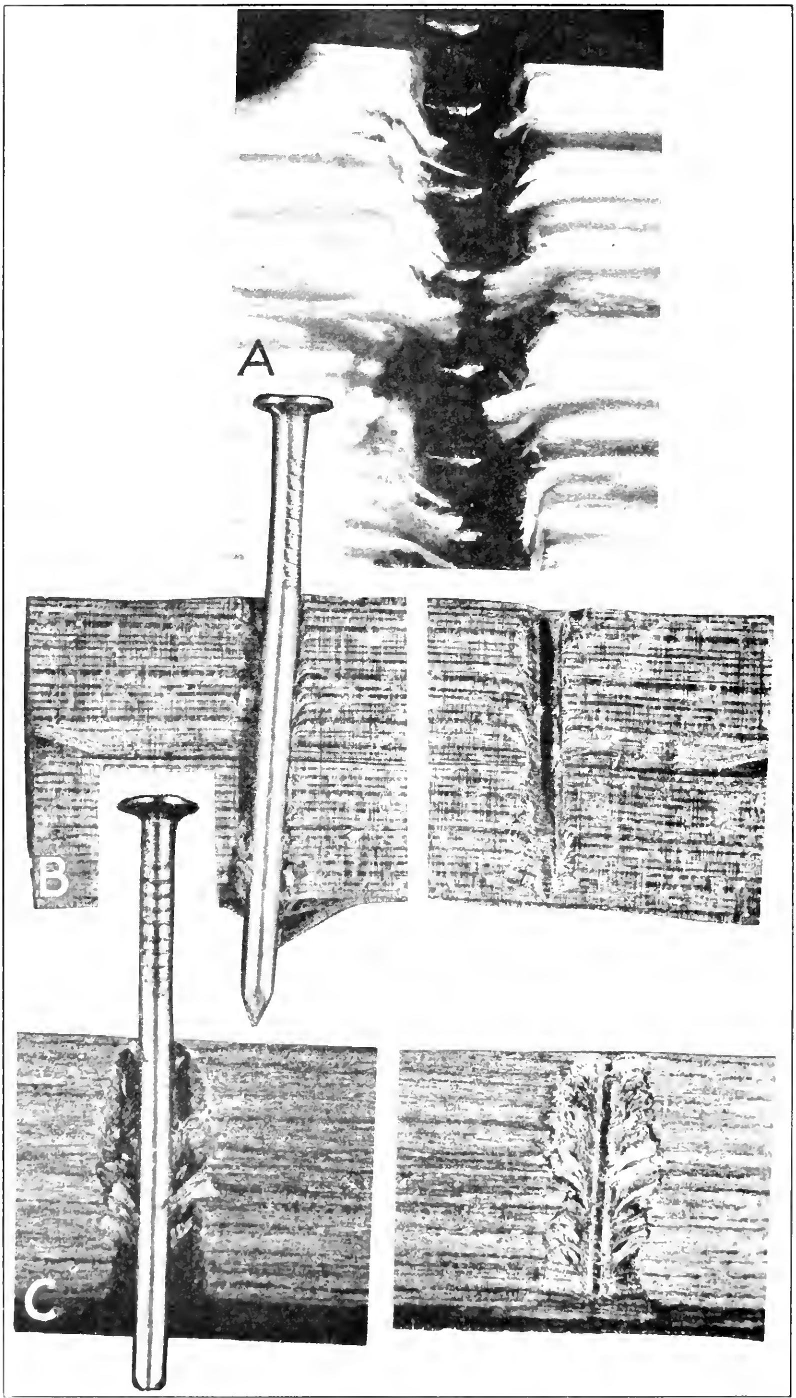
The straight-driven nails have approximately the same holding power as those driven at an angle when pulled in a direction perpendicular to the surface of the board shortly after driving



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Distortion of wood fibers by nails. A, Barbed nail (highly magnified); B, common smooth nail; C, blunt pointed nail shortly after their driving. If drying occurs after the nails are driven, the slant-nailed joints begin to loosen at lower loads than the prependicularly nailed joints, although the loss in ultimate holding power is less than for the perpendicularly-nailed pieces. This indicates that slant nailing is an advantage in box or crate construction if considerable drying occurs after the nails are driven.

CHARACTER OF NAIL SHANK

The nail-holding power of wood also depends on the character of tne nail shank. Cement coating (a composition of resin usually applied hot by nail manufacturers) increases the friction between the nail and wood and thereby increases the resistance to withdrawal. (Figs. 16 and 17.)

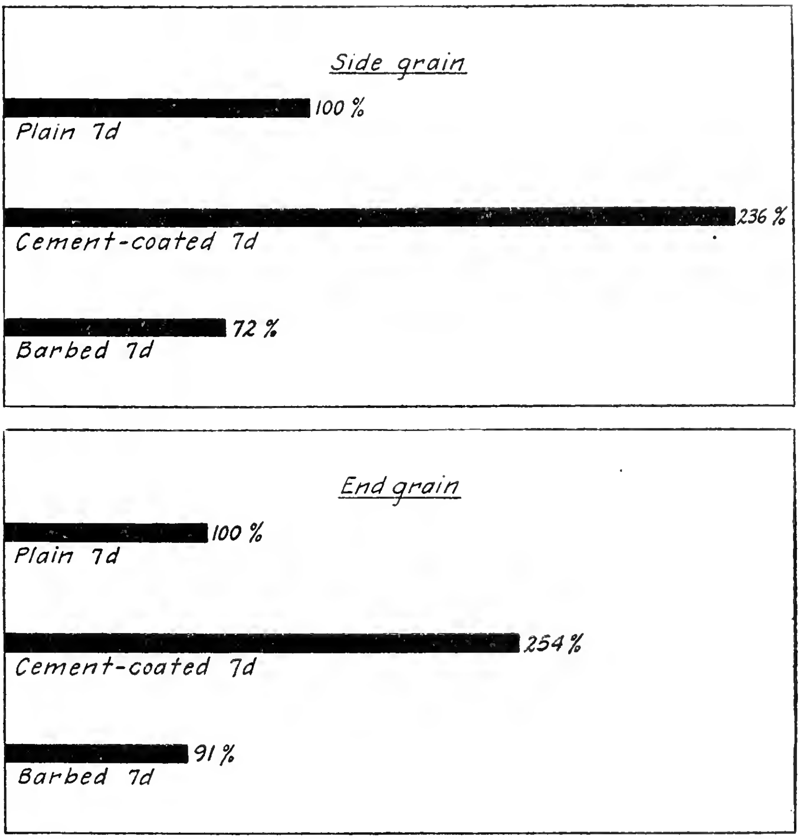


FIGURE 16.—Comparative holding power of different types of nails driven to 1¼ inches in western yellow pine having 8 per cent moisture content and pulled at once. Values are adjusted on the basis of area of contact of a plain sevenpenny nail

Barbed nails are so called because their shanks have a series of small barbs or teeth. When these nails are driven, the barbs distort or break off the wood fibers and pull the fibers down along the side of the nail. This action leaves the surface of the wood in contact with the shank more ragged than is the case with smooth nails. (Pl. 30, A and B.) For this reason the resistance to withdrawal of nails which are driven and pulled immediately is less for barbed than for smooth nails. If driven into green wood which is subsequently dried to a low moisture content, however, the barbed nails hold much better than smooth nails either plain or cement-coated. (Fig. 17.)

The practice of applying talc or graphite to cement-coated nails to facilitate their movement in nailing machines seriously reduces the holding power of these nails. (Fig. 18.)

RESISTANCE TO SPLITTING

The force required to split a piece of wood increases, as a rule, with the density. Nevertheless, the denser woods split more in nailing than the lighter woods because as the density of the wood increases its hardness and consequently the magnitude of the splitting force produced in driving nails increases faster than the

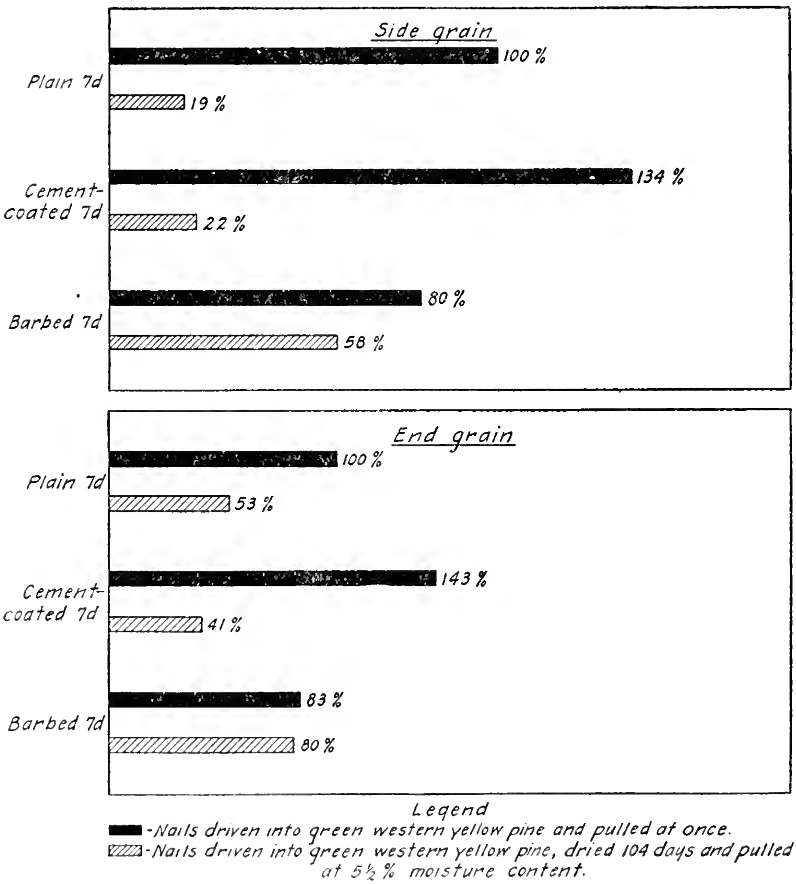


FIGURE 17.—Effect of change of moisture content in wood on the holding power of different types of nails driven into wood in a green condition. Values were adjusted on the basis of area of contact of a plain sevenpenny nail, all nails being driven to 1¼ inches

resistance that the wood offers to splitting. The tendency of wood to split depends very largely upon the size of the nail and the character of the point; less splitting occurs with the smaller nails. Blunt-pointed nails, because of the manner in which they tear and otherwise distort the wood fibers (pl. 30, C), create less splitting force than sharp-pointed nails, which exert a wedging force in penetrating the wood. Blunt-pointed nails ordinarily offer less resistance to withdrawal, however, than sharp-pointed nails, provided no splitting occurs. (Fig. 19.)

Defects, such as knots, cross grain, checks, and shakes, increase the susceptibility of wood to splitting while interlocked grain has the opposite effect.

RESISTANCE TO SHEAR AT NAILS

The resistance that wood offers to the nails shearing the wood out at the ends of the boards and to the heads pulling directly through the boards varies with the species and density, the thickness of the boards, the distance of the nails from the ends of the boards, and the diameter of the nail head. Table 5 shows the influence of various sizes of heads in resisting these failures.

Overdriving nails or imbedding their heads in the wood crushes the fibers and reduces the resistance to the shanks shearing out and the heads pulling through thin boards almost directly in proportion to the amount the nail is overdriven. (Fig. 20.)

SIZE AND NUMBER OF NAILS

One difficulty in container construction is to provide enough nails to fully develop the strength of the wood. If nails are spaced too close in a row they will split the wood, and if too few nails are used the wood between the nails and the ends of the boards will be sheared out.

TABLE 5.—*Effect of the size of nail head on the strength of a nailed joint*

Material	Size of nail	Diameter of head	Tension			Shear [1]		
			Load per nail	Heads off	Nails broken	Load per nail	Heads off	Nails broken
	Penny	*Inch*	*Pounds weight*	*Per cent*	*Per cent*	*Pounds weight*	*Per cent*	*Per cent*
5/16-inch rotary-cut red gum	6	0.36	312	0	0	186	0	0
		.26	257	0	0	155	0	0
		.24	250	0	0	154	0	0
	5	.28	213	100	0	158	33	16
		.22	196	22	0	152	8	8
		.19	212	0	0	164	0	0
	4	.28	239	83	0	173	67	16
		.22	248	100	0	168	33	0
		.19	222	0	0	163	0	0
3/8-inch sawed white pine	6	.36	220	11	0	164	0	0
		.26	194	0	0	139	0	0
		.24	181	0	0	139	0	0
	5	.28	178	33	0	138	33	17
		.22	149	0	0	142	8	8
		.19	122	0	0	134	0	0
	4	.28	154	22	0	172	33	67
		.22	146	0	0	161	11	22
		.19	116	0	0	150	0	0

[1] See Plate 41 for method of test.

The proper size and number of nails depend on the species of wood and the thickness of the parts joined. With some combinations of species and thicknesses of material a large number of small nails are required and, with other combinations a small number of large nails. The length of the nail shank should be such as to prevent the nail from pulling and also to prevent any prying action from splitting the piece holding the point. Nails should be large enough to be driven easily without bending, but should not be so small that in service they will bend back and forth sufficiently to break.

Standard cement-coated "cooler" and "sinker" nails are well proportioned for general use. (See Appendix G, Table 12.) These are as slender as can be driven readily into hardwoods and are not so easily loosened from the wood by the strains caused by rough handling or weaving as are those of a larger diameter and of the same length, and do not break off easily. The heads of "cooler" or "sinker" nails are of sufficient diameter to prevent them from pulling through the wood except where the wood used is very thin.

INFLUENCE OF MOISTURE CONTENT ON THE NAILING QUALITIES OF WOOD

The nailing qualities of wood are influenced very materially by the seasoning condition. Nails can be driven into or withdrawn from green wood more easily than from dry wood. The nail heads also pull through the green wood, and the shanks shear out of the wood at the ends of the board more easily than with dry wood. On the other hand, green wood, because of its softness, is not so susceptible as dry wood to splitting when the nails are driven.

When a nail is driven into a piece of wood the fibers are broken and bent down along the side of the nail or are separated. (Pl. 30, B.) Where the fibers are dry and rigid, as in seasoned wood, the friction between the wood fibers and the nail shank is relatively high; but where the fibers are soft and flexible, as in green wood, the friction is lower. For western yellow pine the difference in friction for green and for dry wood causes approximately 25 per cent difference in nail-holding power.

The fibers which are bent down against the end grain in driving the nail exert a greater pressure against the nail than those which are pushed back against the side grain. This difference in pressure results from the difference in the end compressive strength and side compressive strength of the fibers immediately

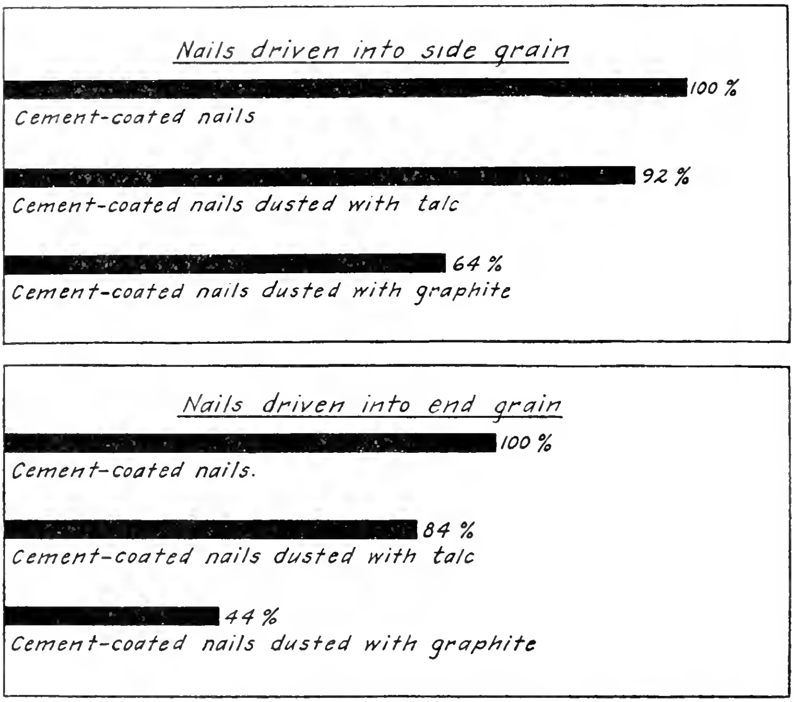


FIGURE 18.—Effect of talc and graphite on the holding power of cement-coated nails. Tests were made with sevenpenny nails driven to 1¼ inches into air-dry western yellow pine and pulled at once

back of those in contact with the nail. If the wood dries after the nail is driven, the nail-holding power is seriously reduced because the shrinking of the fibers, which were bent down against the end-grain fibers, makes the hole larger in the direction of the grain, since the board itself practically does not shrink lengthwise. The shrinkage of the board across the grain tends to make the hole smaller in this direction and so maintains the side-grain pressure on the nail. The loss in nail-holding power of wood with drying and with lapse of time without drying is illustrated in Figure 21.

If nails are driven into dry wood that subsequently undergoes alternate wetting and drying, the fibers will lose their grip on the nails the same as in nails driven into green lumber that subsequently dries out.

SCREW-HOLDING POWER

Screws when properly driven are an admirable fastening for wood. Driving screws almost their full length with a hammer or overdriving them with screw drivers, which is likely to happen in power driving, tears the wood fibers and seriously reduces their holding power. (Table 6.) For maximum efficiency screws should be twisted their full length into bored holes the diameter of which should be 70 to 90 per cent of the root diameter of the screw.

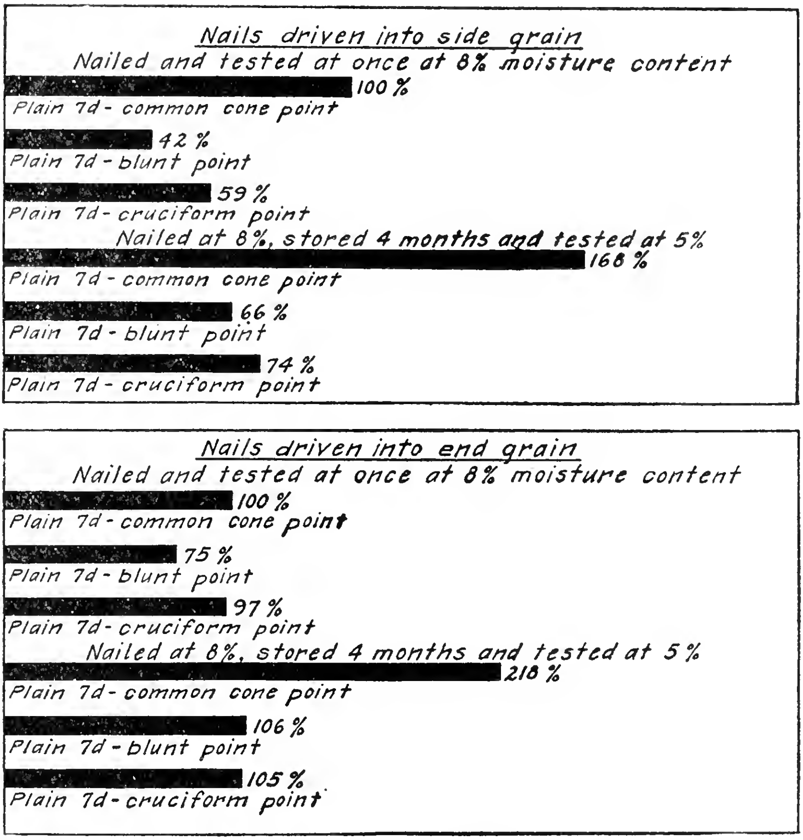


FIGURE 19.—Effect of type of nail point on the holding power of nails. The nails were driven to 1¼ inches in western yellow pine. Values were adjusted on the basis of the area of contact of a plain sevenpenny nail. (See Plate 30, C, for shape of blunt point.)

TABLE 6.—*Resistance to withdrawal of No. 12 wood screws*

[Screws 1¾ inches long, driven to 1-inch depth in holes ⅛ inch in diameter]

Species of wood	Resistance to withdrawal when driven by—			
	Screw driver		Hammer [1]	
	Pounds weight	Per cent	Pounds weight	Per cent
Basswood	478	100	281	59
Southern yellow pine	1, 144	100	681	60
Red gum	687	100	403	59
Birch	841	100	570	68

[1] One final turn with screw driver.

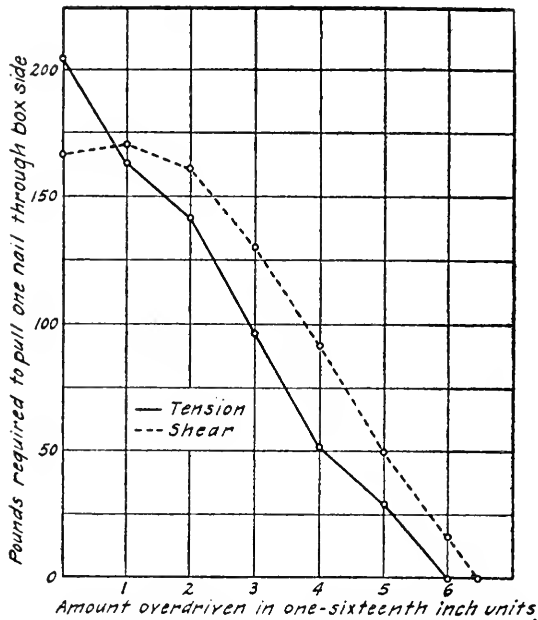


FIGURE 20.—Effect of overdriving nails in and through 5/16-inch box sides

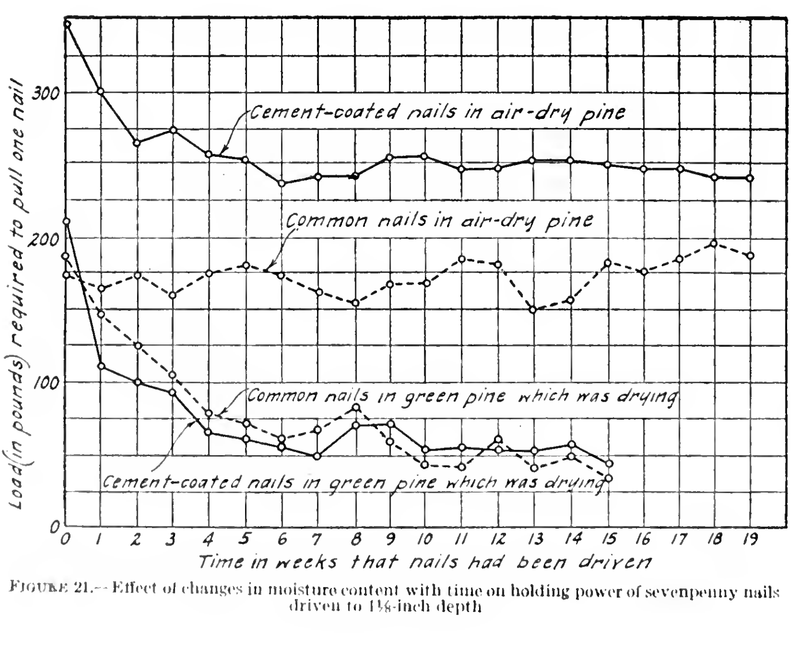


FIGURE 21.—Effect of changes in moisture content with time on holding power of sevenpenny nails driven to 1⅛-inch depth

LAG SCREWS

Holes should first be bored to receive lag screws, and extreme care should be exercised to prevent drawing the screws down so solidly as to strip the threads formed in the wood, since otherwise their holding power is materially reduced. It is usually best to bore a hole of two diameters, the lower portion of the hole being slightly less in diameter than the core of the screw and the upper portion of a diameter to fit the portion of the screw shank adjoining the head.

STAPLES

Staples are most valuable for fastening thin wood and for fastening in place both wire bands and flat metal straps. Their holding power is influenced by the same factors that influence the holding power of nails. Because of their form, staples are not pulled directly through the material or sheared out at the ends so easily as are nails with small heads. To secure good holding power, staples should be driven for a considerable depth into solid wood and, where practicable, they should be driven through and clinched.

Staples have an advantage over nails in holding box straps in place because they do not weaken the strap by puncturing. They also hold the edges of a strap down and, on account of the curvature of the staple head, they do not catch the straps on other boxes.

BOLTS

Bolts, where their use is practicable, are the most dependable fasteners for container construction. Their holding power is usually limited by the resistance of the wood to splitting and shearing. A number of small bolts will produce a more rigid and otherwise stronger joint than a lesser number of larger bolts.

STRENGTH PROPERTIES OF WOOD

The strength properties of wood at right angles to the grain are quite different from the properties parallel to the grain (*15*). The bending strength may be twenty or more times as high when stressed by forces parallel to the grain as when stressed perpendicular to the grain. This difference must be recognized in all wood construction, and the size of parts and fastenings should be such as to utilize to the best advantage these characteristics in wood. The magnitude of the different properties (*15*) varies greatly with different species of wood and for different boards of the same species; in extreme cases some pieces will be more than twice as strong as others of the same species. Nevertheless, half of the clear material of a species usually has strength values within 12 to 20 per cent of the average for the species, the deviations from averages varying with the property and the species under consideration. Average values of various strength and related properties of different species (*12*) are listed in Table 7. A discussion of the significance of the figures in the table, together with examples of their application to various container problems, is given in Appendix F.

TABLE 7.—*Average properties of container woods grown in the United States*

[Based on tests of small, clear specimens.[1] For definition of terms and discussion of table see explanation of table in Appendix F]

HARDWOODS

Common and botanical name of species	Trees tested	Specific gravity, oven-dry, based on volume when green	Weight per cubic foot: Green	Weight per cubic foot: At 12 per cent moisture content	Shrinkage from green to oven-dry condition based on dimensions when green: Radial	Shrinkage: Tangential	Shrinkage: Volumetric (composite value)[2]	Composite strength values[2]: Bending strength	Compressive strength (endwise)	Stiffness	Hardness	Shock resistance
1	2	3	4	5	6	7	8	9	10	11	12	13
	Number		*Pounds*	*Pounds*	*Per cent*	*Per cent*	*Comparative figure*	*Comparative figure*	*Comparative figure*	*Comparative figure*	*Comparative figure*	*Comparative figure*
Alder, red (Alnus rubra)	6	0.37	46	28	4.4	7.3	123	76	82	139	48	71
Ash, Biltmore white (Fraxinus biltmoreana)	5	.51	45	38	4.2	6.9	121	107	108	156	104	114
Ash, black (Fraxinus nigra)	11	.46	53	34	5.0	7.8	144	77	68	126	64	122
Ash, blue (Fraxinus quadrangulata)	5	.53	46	40	3.9	6.5	113	109	107	139	119	147
Ash, green (Fraxinus pennsylvanica lanceolata)	10	.53	49	40	4.6	7.1	122	107	106	157	107	116
Ash, Oregon (Fraxinus oregona)	3	.50	46	38	4.1	8.1	129	88	88	143	94	123
Ash, pumpkin (Fraxinus profunda)	3	.48	46	36	3.7	6.3	113	86	85	118	103	87
Ash, white (Fraxinus americana)	23	.55	48	42	4.9	7.9	132	113	106	168	107	153
Ashes, commercial white (average of four species[3])												
Aspen (Populus tremuloides)	43	.54	48	41	4.6	7.5	126	110	106	161	108	139
Aspen, largetooth (Populus grandidentata)	11	.35	43	27	3.5	6.7	111	63	58	107	31	67
Basswood (Tilia glabra)	10	.35	43	27	3.3	7.9	116	66	69	130	38	63
Beech (Fagus grandifolia)	8	.32	41	26	6.6	9.3	158	61	62	126	31	54
Beech, blue (Carpinus caroliniana)	17	.56	54	45	5.1	11.0	162	102	94	169	96	135
Birch, Alaska white (Betula neoalaskana)	12	.58	53	48	5.7	11.4	184	76	66	114	116	296
Birch, gray (Betula populifolia)	10	.49	48	38	6.5	9.9	166	89	86	161	61	126
Birch, paper (Betula papyrifera)	5	.45	46	35	5.2		147	61	53	85	54	147
Birch, sweet (Betula lenta)	10	.48	50	39	6.3	8.6	158	78	68	137	58	158
Birch, yellow (Betula lutea)	10	.60	57	46	6.5	8.5	154	117	105	207	104	159
Buckeye, yellow (Aesculus octandra)	17	.55	57	43	7.2	9.2	166	106	98	174	86	171
Butternut (Juglans cinerea)	5	.33	49	25	3.5	7.8	118	58	56	112	31	52
	10	.36	46	27	3.3	6.1	100	64	68	115	40	80

Chestnut (Castanea dentata)	10	.40	55	30	3.4	6.7	111	68	70	112	50	69
Cottonwood, black (Populus trichocarpa)	5	.32	46	24	3.6	8.6	123	60	61	119	29	59
Cottonwood, eastern (Populus deltoides)	5	.37	49	28	3.9	9.2	138	62	64	123	36	73
Dogwood, Pacific (Cornus nuttallii)	5	.58	55	45	6.4	9.6	168	86	93	142	116	154
Elm, American (Ulmus americana)	12	.46	54	36	4.2	9.5	145	85	74	130	66	123
Elm, rock (Ulmus racemosa)	10	.57	54	44	4.8	8.1	127	106	97	148	104	189
Elm, slippery (Ulmus fulva)	6	.48	56	37	4.9	8.9	138	92	89	140	72	162
Gum, black (Nyssa sylvatica)	5	.46	45	35	4.4	7.7	133	83	78	118	78	80
Gum, blue (Eucalyptus globulus)	5	.62	70	52	7.6	15.3	226	134	148	233	132	134
Gum, red (Liquidambar styraciflua)	10	.44	50	34	5.2	9.9	150	86	77	134	60	99
Gum, tupelo (Nyssa aquatica)	6	.46	56	35	4.2	7.6	122	82	87	127	78	81
Hackberry (Celtis occidentalis)	6	.49	50	37	4.8	8.9	138	76	72	108	74	145
Hickory, bigleaf shagbark (Hicoria laciniosa)	19	.62	62	48	7.6	12.6	195	126	105	165		308
Hickory, bitternut (Hicoria cordiformis)	11	.60	63	46				127	127	170		227
Hickory, mockernut (Hicoria alba)	19	.64	64	51	7.8	11.0	182	135	122	185		270
Hickory, nutmeg (Hicoria myristicaeformis)	5	.56	60	42				111	104	147		221
Hickory, pignut (Hicoria glabra)	60	.66	64	53	7.2	11.5	182	144	129	198		308
Hickory, shagbark (Hicoria ovata)	24	.64	64	51	7.0	10.5	170	133	123	185		258
Hickory, water (Hicoria aquatica)	2	.61	68	43				128	116	185		189
Hickories, pecan (average of four species [4])	23	.59	62	45	4.9	8.9	137	120	116	165	142	207
Hickories, true (average of four species [5])	122	.65	63	51	7.3	11.4	182	138	123	188		292
Hickories, pecan and true (average of eight species [6])	145	.64	63	50	7.2	11.3	180	135	122	184	142	279
Locust, black (Robinia pseudoacacia)	3	.66	58	48	4.4	6.9	103	157	168	220	161	170
Locust, honey (Gleditsia triacanthos)	6	.60	61	44	4.2	6.6	107	112	111	153	155	144
Magnolia, cucumber (Magnolia acuminata)	5	.44	49	34	5.2	8.8	137	90	88	175	57	103
Magnolia, evergreen (Magnolia grandiflora)	2	.46	62	35	5.4	6.6	122	81	73	136	80	141
Magnolia, mountain (Magnolia fraseri)	5	.40	47	31	4.4	7.5	126	76	73	142	51	81
Maple, bigleaf (Acer macrophyllum)	5	.44	47	34	3.7	7.1	113	83	86	132	73	78
Maple, black (Acer nigrum)	1	.52	54	40	4.8	9.3	140	93	89	149	97	135
Maple, red (Acer rubrum)	14	.49	50	38	4.0	8.2	128	93	87	158	79	110
Maple, silver (Acer saccharinum	5	.44	45	33	3.0	7.2	114	69	71	106	65	93
Maple, striped (Acer pennsylvanicum)	4	.44	37	32	3.2	8.6	121	78	73	135	59	100
Maple, sugar (Acer saccharum)	22	.57	56	44	4.9	9.5	147	114	106	178	115	138
Oak, black (Quercus velutina)	8	.56	63	43	4.5	9.7	142	98	91	146	102	128
Oak, bur (Quercus macrocarpa)	5	.58	62	45	4.4	8.8	129	82	81	104	112	114
Oak, California black (Quercus kelloggii)	10	.51	66	40	3.6	6.6	115	69	72	95	99	76
Oak, canyon live (Quercus chrysolepis)	3	.70	71	54	5.4	9.5	158	110	127	159	181	131
Oak, chestnut (Quercus montana)	5	.57	61	46	5.5	9.7	162	102	94	166	90	107
Oak, laurel (Quercus laurifolia)	5	.56	65	44	4.0	9.9	173	94	90	169	99	120
Oak, live (Quercus virginiana)	5	.81	76	62	6.6	9.5	152	142	130	228	240	148
Oak, Oregon white (Quercus garryana)	10	.64	69	51	4.2	9.0	133	86	89	107	153	127

[1] Based on tests of small clear specimens, 2 by 2 inches in section except radial and tangential shrinkage which are based on width measurements of pieces 1 inch thick, 4 inches wide, and 1 inch long. Bending specimens are 30 inches long; others are shorter, depending on kind of test. This table is for use in comparing species either in the form of clear lumber or in grades containing like defects, except structural material. Structural material which conforms to American lumber standards should be compared by means of allowable working stesses.

[2] For derivation of composite values see Comparative Strength Properties of Woods Grown in the United States (*12*).

[3] *Fraxinus biltmoreana*, *F. quadrangulata*, *F. pennsylvanica lanceolata*, and *F. americana*.

[4] *Hicoria cordiformis*, *H. myristicaeformis*, *H. aquatica*, and *H. pecan*.

[5] *Hicoria laciniosa*, *H. alba*, *H. glabra*, and *H. ovata*.

[6] Species under footnotes 4 and 5 combined.

TABLE 7.—*Average properties of container woods grown in the United States*—Continued

[Based on tests of small, clear specimens. For definition of terms and discussion of table see explanation of table in Appendix F]

HARDWOODS—Continued

Common and botanical name of species	Trees tested	Specific gravity, oven-dry, based on volume when green	Weight per cubic foot: Green	Weight per cubic foot: At 12 per cent moisture content	Shrinkage from green to oven-dry condition based on dimensions when green: Radial	Shrinkage: Tangential	Shrinkage: Volumetric (composite value) [2]	Composite strength values: Bending strength	Compressive strength (endwise)	Stiffness	Hardness	Shock resistance
1	2	3	4	5	6	7	8	9	10	11	12	13
	Number		*Pounds*	*Pounds*	*Per cent*	*Per cent*	*Comparative figure*	*Comparative figure*	*Comparative figure*	*Comparative figure*	*Comparative figure*	*Comparative figure*
Oak, pin (Quercus palustris)	5	.58	63	44	4.3	9.5	143	96	95	167	111	152
Oak, post (Quercus stellata)	10	.60	63	47	5.4	9.8	159	99	89	143	122	130
Oak, red (Quercus borealis)	33	.56	63	44	4.0	8.2	131	99	88	164	103	143
Oak, Rocky Mountain white (Quercus utahensis)	3	.62	62	51	4.1	7.2	121	70	67	78	137	78
Oak, scarlet (Quercus coccinea)	5	.60	62	47	4.6	9.7	140	115	107	181	120	175
Oak, southern red (Quercus rubra)	4	.52	62	41	4.5	8.7	153	83	76	153	86	83
Oak, swamp red (Quercus rubra pagodaefolia)	3	.61	68	48	5.2	10.8	163	131	122	215	123	162
Oak, swamp chestnut (Quercus prinus)	4	.60	65	47	5.9	9.2	180	100	95	171	103	132
Oak, swamp white (Quercus bicolor)	1	.64	69	50	5.5	10.6	172	122	114	184	122	165
Oak, water (Quercus nigra)	5	.56	63	44	4.2	9.3	154	110	95	196	101	138
Oak, white (Quercus alba)	20	.60	62	48	5.3	9.0	153	102	96	152	108	127
Oak, willow (Quercus phellos)	2	.56	67	49	5.0	9.6	175	96	86	167	106	116
Oaks, commercial red (average of nine species [7])	70	.56	64	44	4.2	9.0	143	101	92	168	103	139
Oaks, commercial white (average of six species [8])	45	.59	63	47	5.3	9.3	155	99	93	149	109	125
Oaks, commercial red and white (average of 15 species [9])	115	.57	63	45	4.7	9.1	148	100	92	161	105	134
Pecan (Hicoria pecan)	5	.60	61	47	4.9	8.9	137	110	104	162	142	156
Poplar, balsam (Populus balsamifera)	10	.30	40	23	3.0	7.1	104	48	48	95	25	43
Poplar, yellow (Liriodendron tulipifera)	11	.38	38	28	4.0	7.1	119	71	68	135	40	58

Sycamore (Platanus occidentalis)	10	.46	52	35	5.1	7.6	136	74	76	129	64	78
Willow, black (Salix nigra)	10	.34	50	26	2.5	7.8	126	45	41	70	35	91
Willow, western black (Salix lasiandra)	5	.39	50	31	2.9	9.0	132	67	63	127	50	104
SOFTWOODS												
Cedar, Alaska (Chamaecyparis nootkatensis)	8	0.42	36	31	2.8	6.0	91	80	87	136	53	93
Cedar, incense (Libocedrus decurrens)	8	.35	45	26	3.3	5.7	81	70	81	97	47	53
Cedar, Port Orford (Chamaecyparis lawsoniana)	14	.40	36	29	4.6	6.9	106	82	90	168	48	79
Cedar, eastern red (Juniperus virginiana)	5	.44	37	33	3.1	4.7	78	67	87	80	81	114
Cedar, western red (Thuja plicata)	15	.31	27	23	2.4	5.0	76	60	74	108	38	52
Cedar, northern white (Thuja occidentalis)	5	.29	28	22	2.1	4.7	69	50	52	78	30	47
Cedar, southern white (Chamaecyparis thyoides)	10	.31	26	23	2.8	5.2	83	53	61	93	35	51
Cypress, southern (Taxodium distichum)	26	.42	50	32	3.8	6.2	104	79	92	136	52	76
Douglas fir (Pseudotsuga taxifolia) (Coast type)	34	.45	38	34	5.0	7.8	121	90	107	181	59	81
Douglas fir (Pseudotsuga taxifolia) (Inland Empire type)	10	.41	37	31	4.1	7.6	112	80	90	159	58	72
Douglas fir (Pseudotsuga taxifolia) (Rocky Mountain type)	10	.40	35	30	3.6	6.2	103	75	83	142	52	67
Fir, alpine (Abies lasiocarpa)	5	.31	28	23	2.5	7.1	92	51	57	92	33	36
Fir, balsam (Abies balsamea)	5	.34	45	26	2.8	6.6	103	59	67	118	31	50
Fir, corkbark (Abies arizonica)	10	.28	29	21	2.8	7.4	90	51	57	104	27	38
Fir, lowland white (Abies grandis)	10	.37	44	28	3.2	7.2	105	72	82	156	43	72
Fir, noble (Abies nobilis)	9	.35	30	26	4.5	8.3	126	74	76	150	39	68
Fir, California red (Abies magnifica)	5	.37	48	27	3.8	6.9	114	78	74	134	52	71
Fir, silver (Abies amabilis)	6	.35	36	27	4.5	10.0	142	70	76	147	37	70
Fir, white (Abies concolor)	20	.35	47	26	3.2	7.0	95	72	73	127	42	60
Firs, white (average of four species) [10]	45	.35	41	26	3.8	7.9	110	72	76	141	41	66
Hemlock, eastern (Tsuga canadensis)	20	.38	50	28	3.0	6.8	98	72	79	121	51	67
Hemlock, mountain (Tsuga mertensiana)	10	.43	44	33	4.4	7.4	114	81	88	131	64	99
Hemlock, western (Tsuga heterophylla)	18	.38	41	29	4.3	7.9	120	74	84	144	50	73
Juniper, alligator (Juniperus pachyphloea)	3	.48	42	36	2.7	3.6	73	63	76	60	107	79
Larch, western (Larix occidentalis)	13	.48	48	36	4.2	8.1	129	89	104	153	64	81
Pine, jack (Pinus banksiana)	5	.39	50	30	3.4	6.5	102	64	73	111	48	78
Pine, jeffrey (Pinus jeffreyi)	5	.37	47	28	4.4	6.7	103	68	71	116	44	63
Pine, limber (Pinus flexilis)	2	.37	39	28	2.4	5.1	80	69	69	107	39	54
Pine, loblolly (Pinus taeda)	10	.50	54	38	5.5	7.5	127	93	104	166	62	93
Pine, lodgepole (Pinus contorta)	28	.38	39	29	4.5	6.7	114	67	74	128	41	60
Pine, longleaf (Pinus palustris)	34	.55	50	41	5.3	7.5	124	106	123	189	76	103
Pine, mountain (Pinus pungens)	5	.49	54	37	3.4	6.8	107	91	93	151	64	92
Pine, northern white (Pinus strobus)	18	.34	36	25	2.3	6.0	83	63	67	119	35	55
Pine, Norway (Pinus resinosa)	5	.44	42	34	4.6	7.2	116	85	91	163	46	84

[7] *Quercus velutina, Q. laurifolia, Q. palustris, Q. borealis, Q. coccinea, Q. rubra Q. rubra, pagodæfolia, Q. nigra,* and *Q. phellos.*
[8] *Quercus macrocarpa, Q. montana, Q. stellata, Q. prinus, Q. bicolor,* and *Q. alba.*
[9] Species under footnotes 7 and 8 combined.
[10] *Abies grandis, A. mobilis, A. amabilis,* and *A. concolor.*

TABLE 7.—*Average properties of container woods grown in the United States*—Continued

[Based on tests of small, clear specimens. For definition of terms and discussion of table see explanation of table in Appendix F]

SOFTWOODS—Continued

Common and botanical name of species	Trees tested	Specific gravity, oven-dry, based on volume when green	Weight per cubic foot: Green	Weight per cubic foot: At 12 per cent moisture content	Shrinkage from green to oven-dry condition based on dimensions when green: Radial	Shrinkage: Tangential	Shrinkage: Volumetric (composite value) [2]	Composite strength values: Bending strength	Compressive strength (endwise)	Stiffness	Hardness	Shock resistance
1	2	3	4	5	6	7	8	9	10	11	12	13
	Number		*Pounds*	*Pounds*	*Per cent*	*Per cent*	*Comparative figure*	*Comparative figure*	*Comparative figure*	*Comparative figure*	*Comparative figure*	*Comparative figure*
Pine, pitch (Pinus rigida)	10	.45	50	34	4.0	7.1	110	80	76	146	56	96
Pine, pond (Pinus rigida serotina)	5	.50	49	38	5.1	7.1	115	89	103	154	64	90
Pine, sand (Pinus clausa)	5	.45	38	34	3.9	7.3	104	86	89	135	63	86
Pine, shortleaf (Pinus echinata)	12	.49	51	38	5.1	8.2	128	97	104	170	68	111
Pine, slash (Pinus caribaea)	10	.64	56	48	5.8	8.2	131	116	126	195	93	105
Pine, sugar (Pinus lambertiana)	9	.35	51	25	2.9	5.6	79	64	68	112	38	55
Pine, western white (Pinus monticola)	14	.36	35	27	4.1	7.4	118	69	75	137	35	65
Pine, western yellow (Pinus ponderosa)	31	.38	45	28	3.9	6.3	97	65	69	112	41	58
Spruce, black (Picea mariana)	5	.38	32	28	4.1	6.8	112	68	70	143	40	82
Spruce, Engelmann (Picea engelmannii)	10	.31	39	23	3.4	6.6	102	55	57	100	32	45
Spruce, red (Picea rubra)	11	.38	34	28	3.8	7.8	117	72	80	138	41	68
Spruce, Sitka (Picea sitchensis)	25	.37	33	28	4.3	7.5	116	72	75	144	44	76
Spruce, white (Picea glauca)	15	.37	35	28	4.7	8.2	134	68	70	123	37	67
Spruces (average of red, white, and Sitka) [11]	51	.37	34	28	4.3	7.7	121	71	74	136	42	71
Tamarack (Larix laricina)	5	.49	47	37	3.7	7.4	128	84	96	147	53	85
Percentage estimated probable variation of species average when based on five trees [12]		2.1			5.2	4.0	3.9	2.5	3.3	3.2	2.8	5.0
Percentage estimated probable variation of an individual piece		8.0					12.0	12.0	14.0	18.0	16.0	20.0

[11] *Picea rubra*, *P. sitchensis*, and *P. glauca*.

[12] For percentage estimated probable variation when based on different number of trees see Comparative Strength Properties of Woods Grown in the United States (*12*).

The properties for which values are given in Table 7 are important factors in the design of boxes and crates, but the choice of species is seldom based upon them alone but is based upon the combination of these properties with cost, availability, nail-holding power, tendency to split in nailing, tendency to check and warp in seasoning or with changes of moisture content subsequent to seasoning, color, odor, taste, and other properties and characteristics that can not be expressed numerically.

WEIGHTS OF LUMBER

The unit weight or density is an important consideration in selecting wood for a particular use. Weight not only directly influences the cost both of handling and of transportation, but the weight of dry wood per cubic foot is a very good measure of its strength *(11)* and nail-holding power. Density or weight of dry wood per cubic foot also roughly indicates the shrinking and warping likely to occur with changes in moisture content. Heavy, dense woods are especially desirable where high nail-holding power is important but require more care in nailing to prevent splitting and are less desirable where shrinking and warping must be avoided. The lighter woods, as a rule, give less trouble in seasoning, manufacture, and in storing as lumber, shooks, or completed containers, and may, therefore, be more desirable.

The weight of dry lumber per thousand board feet varies from about 1,800 pounds for very light woods to over 4,000 pounds for very heavy woods. A definite way of expressing the weight of wood is in pounds per cubic foot or per square foot of a specified thickness at a given moisture content or degree of dryness. The approximate average weights of various woods per cubic foot and per square foot of different thicknesses are given in Table 8 for convenience in making comparisons and in estimating weights of containers.

TABLE 8.—*Approximate average weights of wood in pounds per cubic foot and per square foot of various thicknesses at 12 per cent moisture content*

Common name of species	Weight per cubic foot	Weight per square foot for actual thickness in inches of—													
		1	7/8	13/16	25/32	3/4	5/8	1/2	3/8	5/16	1/4	3/16	1/6	1/8	1/10
GROUP 1															
Aspen	27	2.25	1.97	1.83	1.76	1.69	1.41	1.12	0.84	0.70	0.56	0.42	0.38	0.28	0.22
Aspen, largetooth	27	2.25	1.97	1.83	1.76	1.69	1.41	1.12	.84	.70	.56	.42	.38	.28	.22
Basswood	26	2.17	1.90	1.76	1.69	1.63	1.35	1.08	.81	.68	.54	.41	.36	.27	.22
Buckeye, yellow	25	2.08	1.82	1.69	1.63	1.56	1.30	1.04	.78	.65	.52	.39	.35	.26	.21
Cedar, northern white	22	1.83	1.60	1.49	1.43	1.38	1.15	.91	.69	.57	.46	.34	.31	.23	.18
Cedar, Port Oxford	29	2.42	2.11	1.96	1.89	1.81	1.51	1.21	.91	.76	.60	.45	.40	.30	.24
Cedar, western red	23	1.92	1.68	1.56	1.50	1.44	1.20	.96	.72	.60	.48	.36	.32	.24	.19
Chestnut	30	2.50	2.19	2.03	1.95	1.88	1.56	1.25	.94	.78	.62	.47	.42	.31	.25
Cottonwood, black	24	2.00	1.75	1.62	1.56	1.50	1.25	1.00	.75	.62	.50	.38	.33	.25	.20
Cottonwood, eastern	28	2.33	2.04	1.90	1.82	1.75	1.46	1.17	.88	.73	.58	.44	.39	.29	.23
Cypress, southern	32	2.67	2.33	2.17	2.08	2.00	1.67	1.33	1.00	.83	.67	.50	.44	.33	.27
Fir, alpine	23	1.92	1.68	1.56	1.50	1.44	1.20	.96	.72	.60	.48	.36	.32	.24	.19
Fir, balsam	26	2.17	1.90	1.76	1.69	1.63	1.35	1.08	.81	.68	.54	.41	.36	.27	.22
Fir, California red	27	2.25	1.97	1.83	1.76	1.69	1.41	1.12	.84	.70	.56	.42	.38	.28	.22
Fir, lowland white	28	2.33	2.04	1.90	1.82	1.75	1.46	1.17	.88	.73	.58	.44	.39	.29	.23
Fir, noble	26	2.17	1.90	1.76	1.69	1.63	1.35	1.08	.81	.68	.54	.41	.36	.27	.22
Fir, silver	27	2.25	1.97	1.83	1.76	1.69	1.41	1.12	.84	.70	.56	.42	.38	.28	.22
Fir, white	26	2.17	1.90	1.76	1.69	1.63	1.35	1.08	.81	.68	.54	.41	.36	.27	.22
Magnolia, cucumber	34	2.83	2.48	2.30	2.21	2.12	1.77	1.42	1.06	.89	.71	.53	.47	.35	.28
Magnolia, evergreen	35	2.92	2.55	2.37	2.28	2.19	1.82	1.46	1.09	.91	.73	.55	.49	.36	.29
Pine, jack	30	2.50	2.19	2.03	1.95	1.88	1.56	1.25	.94	.78	.62	.47	.42	.31	.25
Pine, lodgepole	29	2.42	2.11	1.96	1.89	1.81	1.51	1.21	.91	.76	.60	.45	.40	.30	.24
Pine, northern white	25	2.08	1.82	1.69	1.63	1.56	1.30	1.04	.78	.65	.52	.39	.35	.26	.21
Pine, Norway	34	2.83	2.48	2.30	2.21	2.12	1.77	1.42	1.06	.89	.71	.53	.47	.35	.28
Pine, sugar	25	2.08	1.82	1.69	1.63	1.56	1.30	1.04	.78	.65	.52	.39	.35	.26	.21
Pine, western white	27	2.25	1.97	1.83	1.76	1.69	1.41	1.12	.84	.70	.56	.42	.38	.28	.22
Pine, western yellow	28	2.33	2.04	1.90	1.82	1.75	1.46	1.17	.88	.73	.58	.44	.39	.29	.23
Poplar, yellow	28	2.33	2.04	1.90	1.82	1.75	1.46	1.17	.88	.73	.58	.44	.39	.29	.23
Redwood	30	2.50	2.19	2.03	1.95	1.88	1.56	1.25	.94	.78	.62	.47	.42	.31	.25
Spruce, Engelmann	23	1.92	1.68	1.56	1.50	1.44	1.20	.96	.72	.60	.48	.36	.32	.24	.19
Spruce, red	28	2.33	2.04	1.90	1.82	1.75	1.46	1.17	.88	.73	.58	.44	.39	.29	.23
Spruce, Sitka	28	2.33	2.04	1.90	1.82	1.75	1.46	1.17	.88	.73	.58	.44	.39	.29	.23
Spruce, white	28	2.33	2.04	1.90	1.82	1.75	1.46	1.17	.88	.73	.58	.44	.39	.29	.23
Willow, black	26	2.17	1.90	1.76	1.69	1.63	1.35	1.08	.81	.68	.54	.41	.36	.27	.22
Willow, western black	31	2.58	2.26	2.10	2.02	1.94	1.61	1.29	.97	.80	.64	.48	.43	.32	.26
GROUP 2															
Fir, Douglas	34	2.83	2.48	2.30	2.21	2.12	1.77	1.42	1.06	.89	.71	.53	.47	.35	.28
Hemlock, eastern	28	2.33	2.04	1.90	1.82	1.75	1.46	1.17	.88	.73	.58	.44	.39	.29	.23

Hemlock, western	29	2.42	2.11	1.96	1.89	1.81	1.51	1.21	.91	.76	.60	.45	.40	.30	.24
Larch, western	36	3.00	2.62	2.44	2.34	2.25	1.88	1.50	1.12	.94	.75	.56	.50	.38	.30
Pine, loblolly	38	3.17	2.77	2.57	2.47	2.38	1.98	1.58	1.19	.99	.79	.59	.53	.40	.32
Pine, longleaf	41	3.42	2.99	2.78	2.67	2.56	2.13	1.71	1.28	1.07	.85	.64	.57	.43	.34
Pine, mountain	37	3.08	2.70	2.50	2.41	2.31	1.93	1.54	1.16	.96	.77	.58	.51	.39	.31
Pine, pitch	34	2.83	2.48	2.30	2.21	2.12	1.77	1.42	1.06	.89	.71	.53	.47	.35	.28
Pine, pond	38	3.17	2.77	2.57	2.47	2.38	1.98	1.58	1.19	.99	.79	.59	.53	.40	.32
Pine, shortleaf	38	3.17	2.77	2.57	2.47	2.38	1.98	1.58	1.19	.99	.79	.59	.53	.40	.32
Pine, slash	48	4.00	3.50	3.25	3.12	3.00	2.50	2.00	1.50	1.25	1.00	.75	.67	.50	.40
Tamarack	37	3.08	2.70	2.50	2.41	2.31	1.93	1.54	1.16	.96	.77	.58	.51	.38	.31
GROUP 3															
Ash, black	34	2.83	2.48	2.30	2.21	2.12	1.77	1.42	1.06	.89	.71	.53	.47	.35	.28
Ash, pumpkin	36	3.00	2.62	2.44	2.34	2.25	1.88	1.50	1.12	.94	.75	.56	.50	.38	.30
Elm, American	36	3.00	2.62	2.44	2.34	2.25	1.88	1.50	1.12	.94	.75	.56	.50	.38	.30
Gum, black	35	2.92	2.55	2.37	2.28	2.19	1.82	1.46	1.09	.91	.73	.55	.49	.36	.29
Gum, red	34	2.83	2.48	2.30	2.21	2.12	1.77	1.42	1.06	.89	.71	.53	.47	.35	.28
Gum, tupelo	35	2.92	2.55	2.37	2.28	2.19	1.82	1.46	1.09	.91	.73	.55	.49	.36	.29
Maple, silver	33	2.75	2.41	2.23	2.15	2.06	1.72	1.37	1.03	.86	.69	.52	.46	.34	.28
Sycamore	35	2.92	2.55	2.37	2.28	2.19	1.82	1.46	1.09	.91	.73	.55	.49	.36	.29
GROUP 4															
Ash, green	40	3.33	2.92	2.71	2.60	2.50	2.08	1.67	1.25	1.04	.83	.62	.56	.42	.33
Ash, white	42	3.50	3.06	2.84	2.73	2.62	2.19	1.75	1.31	1.09	.88	.66	.58	.44	.35
Beech	45	3.75	3.28	3.05	2.93	2.81	2.34	1.88	1.41	1.17	.94	.70	.62	.47	.38
Birch, sweet	46	3.83	3.35	3.11	3.00	2.87	2.39	1.92	1.44	1.20	.96	.72	.64	.48	.38
Birch, yellow	43	3.58	3.13	2.91	2.80	2.69	2.24	1.79	1.34	1.12	.90	.67	.60	.45	.36
Elm, rock	44	3.67	3.21	2.98	2.86	2.75	2.29	1.83	1.38	1.15	.92	.69	.61	.46	.37
Elm, slippery	37	3.08	2.70	2.50	2.41	2.31	1.93	1.54	1.16	.96	.77	.58	.51	.38	.31
Hackberry	37	3.08	2.70	2.50	2.41	2.31	1.93	1.54	1.16	.96	.77	.58	.51	.38	.31
Hickory, pecan and true (average of eight species)	50	4.17	3.65	3.39	3.26	3.13	2.60	2.08	1.56	1.30	1.04	.78	.69	.52	.42
Maple, black	40	3.33	2.92	2.71	2.60	2.50	2.08	1.67	1.25	1.04	.83	.62	.56	.42	.33
Maple, sugar	44	3.67	3.21	2.98	2.86	2.75	2.29	1.83	1.38	1.15	.92	.69	.61	.46	.37
Oak, red	44	3.67	3.21	2.98	2.86	2.75	2.29	1.83	1.38	1.15	.92	.69	.61	.46	.37
Oak, white	48	4.00	3.50	3.25	3.12	3.00	2.50	2.00	1.50	1.25	1.00	.75	.67	.50	.40

Factors that Influence the Weight of Wood

Even in the same species of wood there is considerable variation in the weight of lumber because of differences in density. Pieces containing a high percentage of summer wood, which is the harder layer of the annual-growth ring, have more wood substance and are therefore denser and heavier than pieces containing a lower percentage of summer wood. The swelled butts of trees of some species, such as red gum, tupelo gum, and ash grown in swampy soil, usually contain very light wood with low-strength properties, while higher in the same trees the wood is heavier and stronger.

The water in green wood often weighs more than the wood itself, but in thoroughly air-dry lumber the weight of water is usually 12 to 15 per cent of the weight of wood free of moisture (oven-dry) and in kiln-dry lumber it is often as low as 5 per cent of the weight of wood.

The weight of some pieces of certain species, such as southern yellow pine, western larch, and Douglas fir, is often materially increased by the presence of resin or gum.

FACTORS INFLUENCING THE STRENGTH OF WOOD

The term "strength" as here used is the capacity to resist stress of a single kind, such as strength in tension, strength in compression parallel or perpendicular to the grain, in shear, and strength in bending or shock-resisting capacity.

SPECIFIC GRAVITY

Either the specific gravity or the dry weight of wood furnishes a ready means of estimating the comparative strength of two pieces of wood. Practically all the strength properties increase with the specific gravity of the wood but do not all increase in the same ratio (*11*).

MOISTURE CONTENT

The moisture content is one of the principal factors affecting the strength of wood. As wood dries, most of its strength properties are increased. This increase in strength, however, does not take place until the drying has reached the fiber-saturation point, the condition in which the cell cavities are empty but the cell walls are fully saturated, which is usually at from 25 to 30 per cent moisture content. Figure 22 shows the relation between moisture content and some of the strength properties of a single species. Clear material of the thicknesses ordinarily used for containers, dried to 12 per cent moisture content, may be fully twice as strong in bending as green material, and when kiln dried to 5 per cent its bending strength may be tripled. All the strength properties do not increase in the same ratio with decrease in moisture below the fiber-saturation point. While the average bending strength increases about 4 per cent for each 1 per cent decrease in moisture content at or near 12 per cent, the stiffness increases only 2 per cent. The average shock resistance usually changes but little with change in moisture content.

COMPARISON OF VERTICAL GRAIN WITH FLAT GRAIN

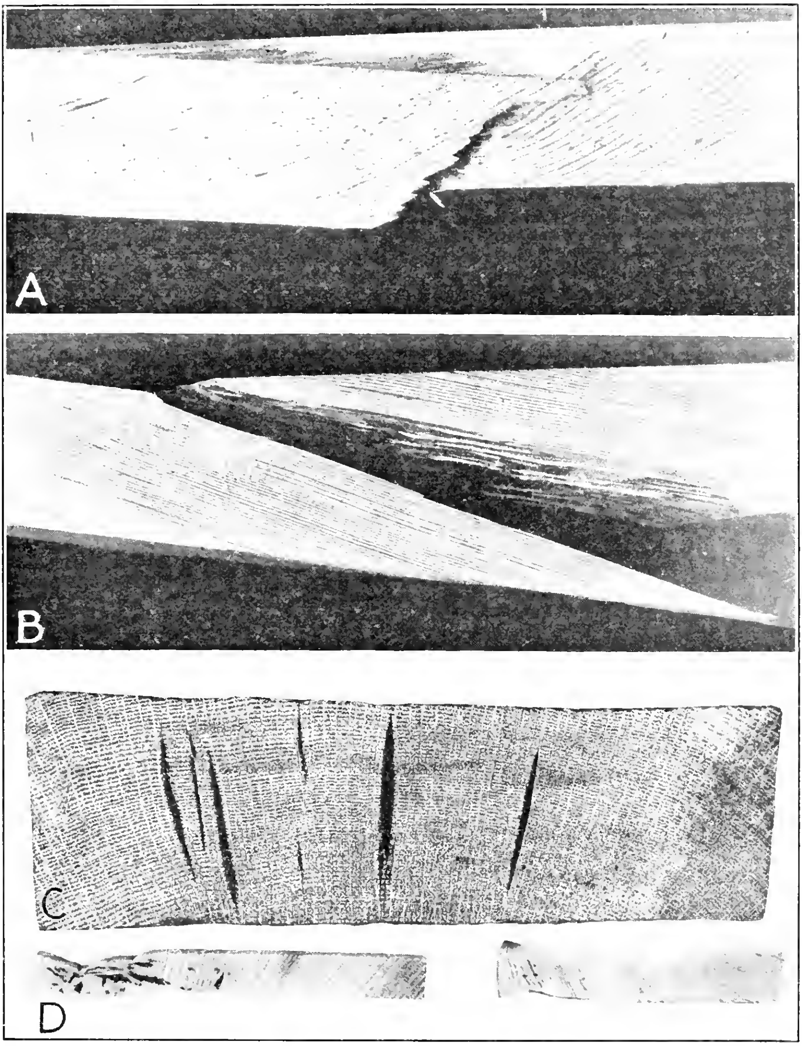
It is common belief that quarter-sawed lumber is stronger in bending than plain-sawed or flat-grain lumber. In tests made by the Forest Products Laboratory, however, no difference of significance in either static bending strength or shock resistance was found between quarter-sawed and flat-grain pieces. Investigation has also shown that in general sapwood is neither stronger nor weaker than heartwood of the same grade, species, and density.

COMPARISON OF SAWED LUMBER WITH ROTARY-CUT LUMBER

Investigations by the Forest Products Laboratory have demonstrated that it is practically impossible to detect any difference in the bending strength or stiffness parallel to the grain of sawed lumber and rotary-cut lumber of the same grade and thickness.

DEFECTS IN CONTAINER MATERIAL

A defect is any irregularity occurring in or on wood that may lower some of the strength, durability, or utility values. Boxes and crates are ordinarily made of low-grade lumber containing defects, some of which seriously affect



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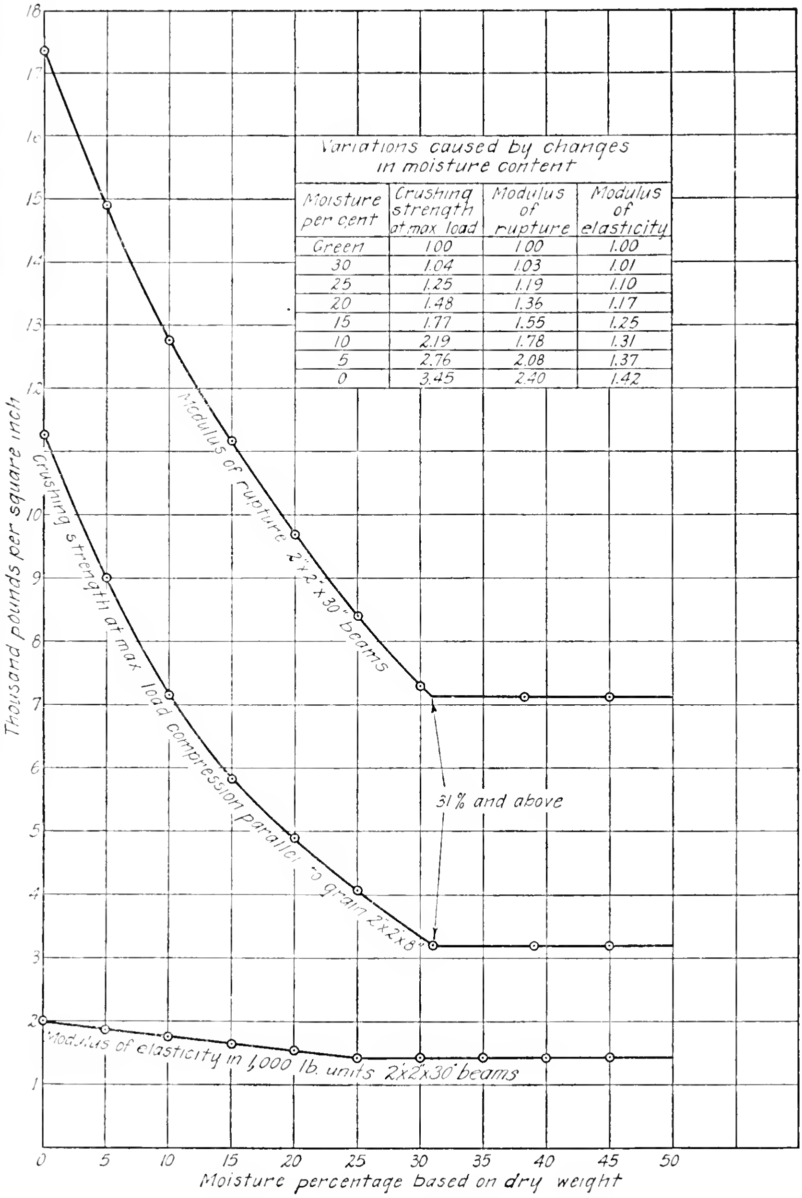
A, Bottom view, and B, side view of a typical bending failure caused by cross grain; C, cross section through a honeycombed plank; D, collapse in boards of different thicknesses



Variations caused by changes in moisture content

Moisture per cent	Crushing strength at max. load	Modulus of rupture	Modulus of elasticity
Green	1.00	1.00	1.00
30	1.04	1.03	1.01
25	1.25	1.19	1.10
20	1.48	1.36	1.17
15	1.77	1.55	1.25
10	2.19	1.78	1.31
5	2.76	2.08	1.37
0	3.45	2.40	1.42

FIGURE 22.—Effect of moisture content of wood on strength of small clear specimens of western hemlock

the strength properties important in containers. Defects that do not appreciably affect the properties important in container material should be allowed in order that waste and cost may be kept at a minimum.

CROSS GRAIN

Cross grain (*28*), in which the wood cells or fibers do not run parallel with the axis or sides of a piece, is one of the most serious defects affecting box and crate material. It reduces the strength in bending and also increases the susceptibility of wood to splitting when nails are driven. Such cross grain occurs in three distinct ways: (1) Around knots and burls, (2) by a growth in which the fibers assume a spiral direction with reference to the axis of the tree trunk, and (3) by sawing lumber at an angle to the axis of the tree. Cross grain is often very difficult to detect except where checks, which invariably follow the grain, are present. Cross grain having a slope from the edge of the board not exceeding 1 in 12 does not materially affect the strength of the piece for container purposes if the piece is used for crate members or as cleats for box ends. For box sides, tops, and bottoms the slope of the grain may be 1 in 10 without impairing the strength of the box. The slope, however, should not exceed these ratios. A typical bending failure in a piece of wood containing excessive cross grain is illustrated in Plate 31, A.

KNOTS

Knots are the most common defects in lumber. Their weakening of the bending strength of lumber is practically proportional to their effective diameter as measured across the width of the board. Since the wood of a knot is harder, stronger, and heavier than the surrounding wood, it might be expected to add strength to the piece. This would be true if it were not for the manner in which knots are formed. A knot is a portion of a branch or limb that has become incorporated in another branch or in the body of the tree. The wood fibers running out into the limb and those passing around the limb and continuing in the main body produce cross grain. Because of the difference in the strength of wood parallel to and perpendicular to the grain, the weakening effect of knots results mainly from the cross grain around them. Checks also develop in knots during seasoning and thus further reduce the strength of knotty lumber. Knot holes and encased knots have no more effect on the bending strength of lumber than intergrown knots because they are accompanied by less cross grain.

DETERIORATION IN SEASONING

Many of the defects, such as checking, warping, and decay, that cause weaknesses in containers, occur while the lumber is in storage or during the process of seasoning (*21*). The extent of such deterioration depends upon the kind of wood, the conditions of seasoning, and the care exercised in piling the lumber. Some of these defects can be prevented entirely, while others can be eliminated only in part.

CHECKING

Checking is due to stresses set up by nonuniform shrinkage. End checking is caused by the wood drying more rapidly at the ends than away from the ends where the drying takes place from the sides only. End checking can often be avoided by painting or coating the ends (*21*) to retard their drying or by reducing the circulation of air around them. Checks reduce the holding power of nails and may develop into splits running the full length of the piece. Surface checks result from the surface drying faster than the interior. Frequently surface checks, formed during the early stages of drying, close up and become invisible during the latter drying. Shrinkage of the central portion of a piece of wood after the surface has dried and set may cause the core or center to check, forming honeycomb. (Pl. 31, C.) These difficulties can be largely overcome by preventing too rapid drying of the surface.

CUPPING

By cupping is meant the curvature of lumber across the grain or width of a piece, which gives it a troughlike appearance. It may be caused by one side drying more rapidly than the other, in which event it is usually temporary. When plain-sawed lumber is dried with insufficient weight on it or is improperly stickered, permanent cupping takes place. In plain-sawed lumber the side that has been toward the center of the tree shrinks less than the other side and thus has a tendency to cause such lumber to cup in drying.

BOWING AND TWISTING

Bowing and twisting are often caused by spiral or by interlocked grain, by differences in longitudinal shrinkage between different parts of the piece, and by other irregularities in structure. These troubles can be prevented to some extent by piling carefully, using sufficient stickers of proper quality and well aligned, leaving no unsupported ends, and weighting the boards both during and after drying.

CASEHARDENING

Casehardening or surface hardening in lumber is caused by too rapid surface drying. It results in stresses being set up in the piece which may cause warping, when the lumber is resawed.

COLLAPSE

An abnormal type of shrinkage that occasionally takes place in drying certain kinds of lumber is called "collapse." The surfaces of collapsed lumber have a caved-in or corrugated appearance when it has been dried. (Pl. 31, D.) Collapse, which occurs only in a few species, results from the cells of the wood collapsing as the water leaves them during the drying process. It does not occur in the sapwood or at the ends or edges of the lumber where air can readily enter the wood to replace the water and thus prevent it. Avoiding collapse is very difficult, although it is more likely to occur in wood green from the saw that is dried in kilns at high temperatures than in air seasoning or in kiln drying at lower temperatures.

BLUE STAIN

Blue stain, or sap stain, is a blue discoloration of the sapwood. It is very common in the pines and red gum and occurs also in the sapwood of other species. Blue stain is due to a fungus that lives on the sap in the cells. It does not destroy the wood or injure its strength, and is objectionable chiefly on account of the discoloration it produces. Its presence, however, is an indication that the material has been subjected to conditions conducive to the growth of wood-destroying fungi. Bad staining may make the presence of decay hard to detect.

Blue stain may occur in the log or in freshly sawed lumber. The fungus which produces blue stain can thrive only as long as the sapwood is moist; therefore converting logs into lumber promptly and piling the lumber so that it will season as rapidly as possible greatly arrests, though it does not prevent, this discoloration *(20)*. Blue stain makes rapid progress in green lumber during warm, humid weather, especially when the lumber is close piled, as it usually is in transit. Under such conditions the stain may penetrate all of the sapwood in a few days. If lumber is not blue stained when placed in a kiln, kiln drying will prevent blue staining, provided the lumber is subsequently kept dry. Kiln drying the lumber immediately after sawing, however, is ordinarily done only with the higher grades, although some mills also run the lower grades of lumber through a kiln. Another preventive measure, although not always completely effective, consists in dipping the lumber as it comes from the saw in an antiseptic solution, such as sodium bicarbonate. Occasionally, blue-stained lumber is dipped in stains of various colors to give it a more pleasing appearance.

BROWN STAINS

Brown stains are brown discolorations occurring in wood. They occur during both air seasoning and kiln drying and are sometimes called yard brown stain and kiln brown stain. The yard brown stains occur as a yellow to dark-brown discoloration, chiefly in air-seasoned sapwood and heartwood stock of sugar pine, western yellow pine, and northern white pine. The kiln brown stain is also yellow to dark brown in color and develops during kiln drying of the heartwood and sapwood stock of the species just mentioned. Kiln brown stain is of a chemical nature. The brown stain occurring during air seasoning, while definitely known in some cases to be due to a chemical reaction, in other cases may be due to fungous action. The cause of the chemical brown stains is not positively known. When brown stain occurs, it is usually just below the surface of rough boards and is therefore seldom detected until after planing. The foregoing brown stains do not injure the strength of wood, nor are they an indication that decay might be present. There are, however, brown discolorations due to both wood-destroying fungi and to too high kiln temperatures, both of which are injurious to the strength properties of wood.

DECAY

Decay is a disintegration of the wood substance resulting from the action of wood-destroying fungi (*17*). Decay is sometimes found in low-grade material used for containers. It very seriously affects the strength properties and nail-holding power of the wood and should not be allowed in parts where strength is important.

In order that decay may take place, the wood must be moist and the temperature not too low. Wood dried below 20 per cent moisture content and kept from reabsorbing moisture rarely decays; therefore, box and crate lumber dried to a moisture-content range from 12 to 18 per cent practically does not decay as long as it remains in that condition. Although decay is not so rapid in action as sap stain, it may seriously reduce the strength of some woods in three or four months during warm weather, especially when close piled. Decay, including the so-called dry rot, can be prevented in stored lumber (*9*) by piling it properly under sanitary conditions and keeping it dry.

INSECT ATTACK

Certain woods are subject to insect attack in the green lumber, some in dry lumber, and some in insufficiently seasoned lumber. The sapwood of some seasoned hardwoods is subject to attack by an insect known as the powder-post beetle. Hickory, ash, and oak are most subject to this injury, but maple, butternut, elm, poplar, sycamore, and other species are also attacked. The chestnut lumber that is available for boxes and crates almost always contains small wormholes (*7*). These, however, have only a very slight effect on the strength, and if the material is otherwise sound, it is quite satisfactory for this purpose. Some countries in order to avoid the introduction of injurious pests prohibit the entrance of products made from lumber which has been attacked by insects.

Plywood

In designing shipping containers it is not always possible to so proportion the dimensions of lumber as to obtain uniformly the necessary strength. This is caused by the difference in the strength properties of the wood parallel to and perpendicular to the grain. The difficulty can, to a large extent, be overcome by building up plywood to obtain greater equality of properties in the two directions. A symmetrical plywood construction with minimum tendency to warp may be produced by gluing an odd number of sheets of veneer or rotary-cut lumber together with the grain of each piece at right angles to that of the piece next to it.

The strength properties of plywood depend upon the species of wood and the number and thicknesses of the plies. Table 9 affords data on the effect of the number of plies on the strength properties of plywood of the same total thickness. This table shows that increasing the number of plies decreases the strength parallel to the face plies and increases the strength perpendicular to the face plies. Consequently, the strengths in the two directions become more nearly equal as the number of plies is increased. Table 9 shows also that the resistance of plywood to splitting increases rapidly with the number of plies. When plywood is composed of a very large number of plies of the same thickness or if the middle layer of 3-ply stock is about seven-tenths the total thickness, the bending strength is about the same either parallel or perpendicular to the grain of the face plies (*4*, *5*).

Table 9.—*Effect of the number of plies on the strength properties of plywood of the same total thickness*

Number of plies	Bending strength			Strength in tension			Resistance to splitting
	Parallel [1]	Perpendicular [2]	Ratio of perpendicular to parallel	Parallel [1]	Perpendicular [2]	Ratio of perpendicular to parallel	
	Per cent	*Per cent*		*Per cent*	*Per cent*		*Per cent*
3	100	100	20	100	100	58	100
5	74	167	15	96	113	68	185
7	72	193	54	90	119	78	235
9	51	182	72	77	109	83	340

[1] "Parallel" means with stress parallel to grain of face plies.
[2] "Perpendicular" means with stress perpendicular to grain of face plies.

A further advantage of plywood is that its dimensions change very little with changes in moisture content. A glued joint is more likely to fail where plywood is made of thick plies than where it is made of thin plies because greater stresses in the thick material are occasioned by the tendency to shrink or swell with changes in moisture content. Plies one-tenth inch or more in thickness are likely to fail either in the glue or in the wood under such stresses.

Comparison of Kiln Drying and Air Drying

The relative merits of kiln drying lumber as compared with air drying it depend upon a number of considerations. Therefore, no general statement can be made in favor of the one or the other process that will hold for all conditions. Enough experimental work has been done, however, to indicate that with proper care all kinds of lumber can be dried in a kiln with results fully as good in quality of output as those that can be obtained with air drying. Although low-grade lumber is used for boxes and crates the strength properties are of prime importance and improper kiln drying will render the lumber unsuitable for this purpose. (See Appendix C.)

The two principal advantages of kiln drying over air drying are that it reduces the time required to dry the lumber and that the lumber can be dried to the desired moisture content even during damp weather without detriment to strength. Lumber 1 inch thick requires from two months to a year for air drying, but green stock of this thickness can, as a rule, be kiln-dried for box purposes in 15 days or less. Veneer or rotary-cut lumber three-sixteenths inch thick requires from 6 to 12 days for air drying; the same material can be kiln-dried in about 12 hours.

SPECIAL REQUIREMENTS OF CONTAINER WOODS

TASTE AND ODOR

Containers for some kinds of food must be free from taste or odor that will taint the contents. There is little systematic information on the taste and odor imparted to foodstuffs by various woods (*2, 10, 22, 26*). Seemingly, a wood may be entirely satisfactory for one commodity but may seriously taint another commodity. Some woods have a very strong odor when green that is not present when the wood is dry. It is advisable to thoroughly test woods for objectionable tastes and odors before using them for food containers.

CAPACITY TO STAY IN PLACE

Shrinking, cupping, bowing, and twisting are occasioned by the drying of lumber but do not occur until the wood has reached the fiber-saturation point. Woods containing cross or interlocked grain bow or twist more with drying than straight-grained wood. The softwoods or coniferous species usually shrink and swell less with changes in moisture content and therefore stay in place where built into a container better than the hardwoods. Twisting and cupping of the lumber place additional stress on the nails, thereby reducing the effective strength of the container in withstanding the hazards of transportation.

APPENDIX B. CONTAINER WOODS

DISTRIBUTION OF CONTAINER WOODS

The chief factors influencing the choice of species of wood for shipping containers are cheapness, availability (*3*), light weight, and freedom from splitting, and for some commodities lack of imparting taste and odor. Boxes and crates are usually manufactured from the lower grades of lumber. In some of the Eastern States mill-run second-growth stock is used for box construction, and in the Western States the log run cut from certain of the little-used species is sometimes used. In all regions of the United States many boxes and crates are manufactured of rotary-cut lumber or veneer from very high-grade logs.

The species and grade of lumber used in any region is determined by economic conditions including the transportation facilities available. Some of the largest box-manufacturing States produce little of the lumber used for boxes. In some States this situation is occasioned by a lack of local timber. In other States local species are available to meet the needs for containers, but are not used because of the large amount of low-grade lumber produced in other States, which is shipped in and sold at a price below that of the local species.

Large quantities of nailed and locked-corner boxes and some wire-bound boxes are manufactured in the New England States from second-growth northern white pine. Birch plywood from virgin stands and spruce cleats from second-growth stands are also manufactured in the New England States in large quantities for use in boxes. In Virginia and North Carolina second-growth southern yellow pine furnishes most of the wood for nailed boxes and red gum most of the rotary-cut lumber for plywood boxes. Georgia and Florida produce much rotary-cut southern yellow pine that is used locally for fruit and vegetable containers. The States in the lower Mississippi Valley not only supply material for their own containers but also supply much rotary-cut and sawed red gum and southern yellow pine to the box industry of the North Central States. In the Pacific coast and Rocky Mountain regions, western yellow pine, Sitka spruce, western hemlock, Douglas fir, and white fir are the woods most used for boxes and crates. The northern Central States use large quantities of their local species, but these do not meet all their needs. Northern white pine is the principal local species used in the northern Central States for boxes and crates though

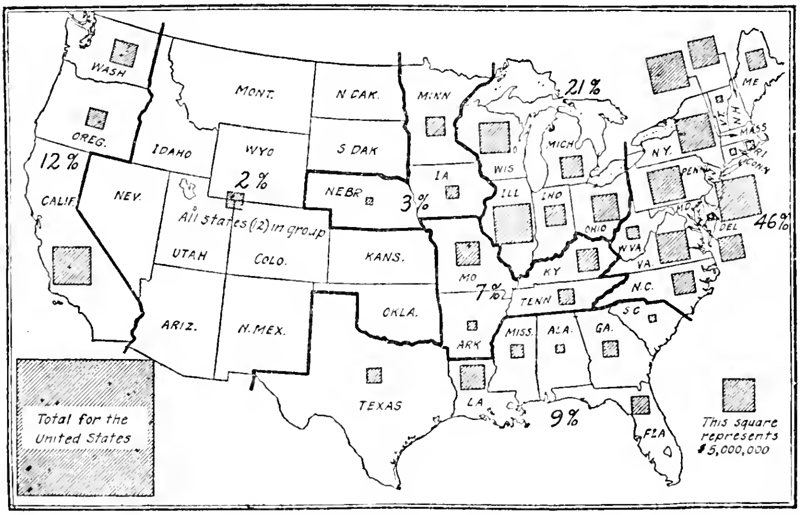


FIGURE 23.—Annual percentage of cost of material for the manufacture of packing boxes and fruit and vegetable packages, by regions, for 1925

smaller quantities of eastern hemlock, basswood, aspen, beech, birch, and maple are used. The beech, birch, and maple are used principally for crating, for resawed wire-bound boxes, and for plywood boxes.

New Jersey, Illinois, New York, and Pennsylvania are among the largest box-manufacturing and box-consuming States; yet they produce relatively little box lumber. Ohio, Maryland, and Indiana are of medium rank in box manufacturing, yet they also produce little box lumber. Colorado has an abundant stand of local timber; yet most of the box shooks used there are shipped in from the Pacific coast and the Inland Empire.[5] The annual combined cost of material used for packing boxes and for fruit and vegetable packages in the United States (*13*, *24*) for 1925 is illustrated graphically in Figure 23. The States in the lower Mississippi Valley and those on the Pacific coast, which are the largest lumber-producing States, consume a relatively small amount of the lumber used for boxes and crates.

To satisfy the demand in the northern Central and Eastern States for containers, large quantities of box lumber and box shooks are brought from distant points. From the region south of the Ohio and Potomac Rivers box lumber moves northward to consuming points in two general currents, separated by the

[5] The wooded area lying in northwestern Montana, Idaho north of the Salmon River, Washington east of the Cascade Mountains, and the northeastern tip of Oregon.

Appalachian Mountains; second-growth loblolly and other southern yellow pine from Virginia and the Carolinas goes northward east of the Allegheny Mountains as far as Rhode Island and Connecticut, while from the Central and Gulf States species such as southern yellow pine, red gum, cypress, and cottonwood move approximately northward. Illinois, Indiana, Ohio, and southern Michigan are common meeting grounds for competition among woods from different regions. Northern white pine from the Lake States, principally Minnesota, Wisconsin, and northern Michigan, goes into Chicago and its vicinity in competition with southern yellow pine and red gum from the South, and western yellow pine and Sitka spruce from the Pacific coast. These western species are also shipped through the Panama Canal to the Atlantic seaboard.

CLASSIFICATION OF CONTAINER WOODS

To facilitate the selection of species of wood for use in box design, the principal woods used for shipping containers have been divided into four groups,[6] as listed on pages 103 and 104. Many of the woods included in this classification are available only in limited quantities; however, many of them may be mixed together to furnish boxes in large quantities, and it is therefore important to know which species may be mixed for use as a single species in design.

Of the 32 species of wood listed, probably 10 furnish less than 5 per cent of the total lumber used for boxes and crates; however, even this small percentage of these species amounts to more than 150,000,000 board feet of lumber annually for boxes and crates (*13*).

In classifying these woods, consideration has been given to their nail-holding power, tendency to split in nailing, strength as a beam, and shock-resisting capacity. In any classification of this sort there are certain to be some kinds of wood that are on the border line between two groups in some particular property; therefore no classification will accurately fit all species. This grouping does not mean that the species within a group are equal in every respect for containers, nor does it mean that the woods in one group are better for all containers than the woods in another group, but it does mean that the woods in each group as a whole possess outstanding characteristics that make them the best for particular types of containers and conditions of service. This is also true to some extent for species within a group, but, in general, specifications that produce a well-balanced container from one species will likewise produce a well-balanced container from other species within the same group. In other words, the species within a group may be mixed together or used interchangeably under the same specification without any great error.

Group 1 embraces the softer woods of both the coniferous and the broad-leaved species. These woods are relatively free from splitting in nailing, have moderate nail-holding power, moderate strength as a beam, and moderate shock-resisting capacity. They are soft, light in weight, easy to work, hold their shape well after manufacture, and, as a rule, are easy to dry.

Group 2 consists of the heavier coniferous woods and includes no hardwood species. These woods usually have a pronounced contrast in the hardness of the spring wood and the summer wood. They have greater nail-holding power than the Group 1 woods, but are more inclined to split and the hard summer wood bands often deflect the nails and cause them to run out at the side of the piece.

Group 3 consists of hardwoods of medium density. No coniferous species are included. These woods have about the same nail-holding power and strength as a beam as the Group 2 woods, but are less inclined to split and shatter under impacts. Group 3 species are the most useful woods for box ends and cleats. They also furnish most of the rotary-cut lumber for wire-bound and plywood boxes.

Group 4 woods are hardwood species. They have both the greatest shock-resisting capacity and the greatest nail-holding power, but, because of their extreme hardness, they present difficulties with respect to the driving of nails and also have the greatest tendency to split at the nails. They are the heaviest and hardest domestic woods and are quite difficult to work. They are especially

[6] This classification of species of wood was first made in 1913. It has been widely accepted by interested organizations, such as the American Society for Testing Materials, various box manufacturers' associations, Bureau of Explosives, Consolidated Freight Classification Committee, Railway Express Agency, Freight Container Bureau, National Canners' Association, National Wholesale Grocers' Association, U. S. War Department, and Federal Specification Board. It has been included in practically all principal specifications for boxes and crates as a basis for defining requirements both for thicknesses of box and crate parts and for nailing.

useful where high nail-holding power is required, and many of them make excellent rotary-cut lumber for wire-bound and plywood boxes.

In selecting container woods it is well to know not only to what extent the species possess the different properties on which the grouping is based but also their availability and those of their general characteristics that are not indicated by this grouping or by the tabulated figures given in Tables 1, 2, 3, 4, 7, and 8. The following is a brief description of the availability and general characteristics of the more important container woods.

DESCRIPTION OF BOX AND CRATE WOODS

For convenience of comparison, the woods most similar in appearance (*11*) and in the properties essential for box construction are considered together. The forest regions in parenthesis following the names of the species refer to the regions in which the trees grow as indicated in Figure 24. Although the geographical distribution of each species extends beyond the limits of the regions indicated (*18*), these regions are the principal sources of supply of the lumber.

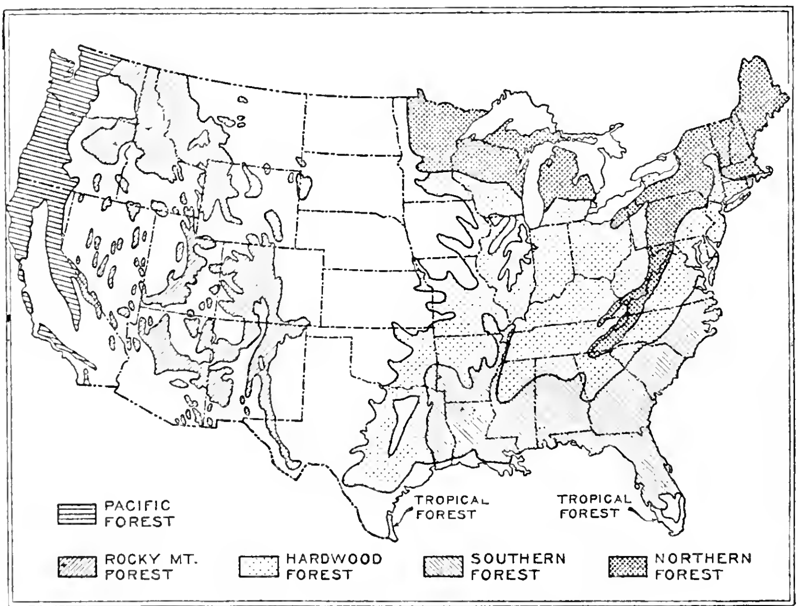


FIGURE 24.—Forest regions of the United States

The comparative strength properties of the species used for containers are given in Table 7, and the nail-holding power of some of these species is given in Table 4.

GROUP 1

Group 1 includes two subgroups, as follows:

CONIFERS (SOFTWOODS)

COMMON NAME [7]

Cedar, northern white.
Cedar, Port Orford.
Cedar, western red.
Cypress, southern.
Fir, alpine.
Fir, balsam.
Fir, California red.
Fir, lowland white.
Fir, noble.
Fir, silver.
Fir, white.
Pine, jack.
Pine, lodgepole.
Pine, northern white.
Pine, Norway.
Pine, sugar.
Pine, western white.
Pine, western yellow.
Redwood.
Spruce, Engelmann.
Spruce, red.
Spruce, Sitka.
Spruce, white.

[7] Species names used in this bulletin are according to Check List of Forest Trees of the United States (*18*). Scientific names are given in Table 7.

Broad-leaved (Hardwoods)

COMMON NAME

Aspen.	Chestnut.	Poplar, yellow.
Aspen, largetooth.	Cottonwood, black.	Willow, black.
Basswood.	Cottonwood, eastern.	Willow, western black.
Butternut.	Magnolia, cucumber.	
Buckeye, yellow.	Magnolia, evergreen.	

The Group 1 species furnish about one-half of the total lumber used for boxes and crates. Most of the lumber furnished by the group is northern and western white pine and western yellow pine. Jack pine, lodgepole pine, Norway pine, the spruces, and the true firs are other species of Group 1 that resemble the white pines and western yellow pine in general appearance and in some properties.

The most effective way to describe species is to classify them into small groups and to compare them within such groups as follows:

Northern white pine (northern forest).[8]
Sugar pine (lower part of Pacific forest).
Western white pine (northern portion of Pacific and upper part of Rocky Mountain forests).

The greatest production of northern white pine box lumber is in the New England States. The wood from the white pines is light colored and straight grained, and the annual growth rings are distinct even though they are without a pronouncedly harder and denser summer-wood band. The heartwood of the northern white pine and western white pine is cream colored to light reddish or yellowish brown, but the heartwood of sugar pine is light brown and seldom reddish. The wood from the white pines has a slight, pleasantly resinous odor, but the wood is almost tasteless except that the sugar pine may have resinous exudations, which give it a sweetish taste. The wood of sugar pine often has a slightly coarser texture than that of the other white pines. The white pines shrink and swell less than most woods. The old-growth northern white pine warps the least of any of the native softwood species.

Jack pine (northern portion of northern forest).
Lodgepole pine (northern and central portions of Rocky Mountain and upper portion of Pacific forests).
Norway pine (northern portion of northern forest).
Western yellow pine (Rocky Mountain and southern portion of Pacific forests).

The pines listed above are similar in appearance and properties to the white pines. Western yellow pine in merchantable stands has the widest geographical distribution of any species in North America. Most of the box lumber from western yellow pine is produced in the Pacific Coast States and in Idaho. The wood from the jack, lodgepole, Norway, and western yellow pines is light colored and straight grained. The annual rings of the young trees have a distinct band of summer wood, whereas the summer-wood layers in the outer annual rings of the old trees may be narrow and inconspicuous. These pines have a resinous odor but are almost tasteless. The wood shrinks and swells slightly more than the white pines but is harder and holds nails better. Lodgepole pine is not generally used for containers but will no doubt be more in demand in the future. There is evidence that boxes made of this wood when properly dried are equivalent in strength to those made of western yellow pine.

Engelmann spruce (Rocky Mountain forest).
Red spruce (eastern half of northern forest).
Sitka spruce (upper half of Pacific forest).
White spruce (northern portion of northern forest).

The wood of the foregoing species resembles that of the white pines in texture, but has a silky sheen. The heartwood of the white, red, and Engelmann spruce is as light colored as the sapwood, but the heartwood of the Sitka spruce has a reddish tinge. The annual rings of the spruces are clearly defined by a distinct band of summer wood. The pocked or dimpled appearance on the split tangential surfaces of Sitka spruce serves to distinguish it from the reddish-tinged pieces of Douglas fir, a Group 2 wood. The nailing qualities and the strength properties of the spruces are similar to the properties of the white pines except that the spruces are tougher. The spruces are practically tasteless and odorless.

Alpine fir (Rocky Mountain and upper half of Pacific forests).
Balsam fir (northern forest).
California red fir (lower half Pacific forest).
Lowland white fir (upper halves of Rocky Mountain and Pacific forests).
Noble fir (upper half of Pacific forest).
Silver fir (upper half of Pacific forest).
White fir (lower halves of Rocky Mountain and Pacific forests).

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[8] The names in parentheses refer to the forests in which the trees grow as indicated in Figure 24.

The wood from the true firs just listed[9] is whitish in color and often has a reddish-brown tinge, which is especially noticeable in the summer-wood bands. This condition produces a sharp color contrast in each ring, which is a distinctive characteristic in most of the woods of the true fir group. The wood is nearly uniform in density. The firs, though somewhat lighter in weight, resemble in general appearance the eastern and the western hemlocks, which are Group 2 woods. The difference in color between the spring-wood and summer-wood bands of the firs is usually sufficient to distinguish the firs from the more uniformly colored hemlocks. Alpine fir has a distinctly rank odor even when a fresh cut is made in dry wood, and white fir has a very rank odor when green. The other true firs are without marked characteristic odor or taste. Many of these firs when green contain high percentages of moisture and are more difficult to dry than the pines and the spruces. The true firs warp more and have a greater tendency to split at the nails than the white pines, spruces, and the softer yellow pines.

Northern white cedar (northern portion of northern forest).
Port Orford cedar (Pacific forest restricted range, southwest Oregon and northwest California).
Western red cedar (upper half Pacific forest).

The cedars furnish less than 1 per cent of the total lumber used for boxes and crates. The northern white cedar and western red cedar are among the softest and weakest native woods; they have very low nail-holding power and are not readily split by nails. The heartwood of red cedar is reddish brown and has a characteristic odor and a somewhat bitter taste. The annual rings are distinct, moderate in width, with a thin, but well-defined, band of summer wood. Northern white cedar often has very narrow annual rings; it resembles western red cedar in odor and taste but averages lighter in weight, has slightly lower strength properties, and usually lacks the reddish hue. Both these species are relatively free from splitting at the nails, and for best results they should be fastened with slightly larger nails than other Group 1 woods. The wood of Port Orford cedar is lighter in color, heavier, less spongy, and has higher strength properties and nail-holding power than the other cedars. It has a pronounced odor, and its taste is sometimes compared to that of ginger. The cedars are easy to dry and have low shrinkage.

Southern cypress (southern forest).
Redwood (southern portion of Pacific forest near the Pacific coast).

Cypress and redwood are quite variable in color and weight. Commercially, the common cypress is classed as "white," "yellow," "red," or "black," although it is almost all derived from the same botanical species. The wood of the cypress and of the redwood somewhat resembles that of the cedars in appearance. The redwood, however, is tasteless and odorless, whereas the cypress, though practically tasteless, has a rancid odor when green very unlike the aromatic odor of the cedars. The odor of dry cypress is less pronounced, but is noticeable in sawing. The annual rings of cypress usually are irregular in width and outline. The summer wood is distinct and narrow, although sometimes it is wider than the summer wood in the cedars. The heartwood of the redwood, as a rule, is a deep reddish brown; the dense bands of summer wood make its annual rings very distinct. Redwood varies somewhat more than most species in density and strength properties. It is considered difficult to nail without splitting.

Aspen (northern, hardwood, Rocky Mountain, and Pacific forests).
Aspen, largetooth (northern and north portion of southern forests).
Basswood (northern and hardwood forests).
Buckeye, yellow (hardwood forest).
Cottonwood, black (Pacific forest).
Cottonwood, eastern (northern portion of northern forest, and hardwood and southern forests.)
Willow, black (northern and southern forests).
Willow, western black (Pacific and southern Rocky Mountain forests).

The species named are the softest of the native hardwoods, and are softer than many of the coniferous species or so-called softwoods, from which they are readily distinguishable by their minute structural characteristics. Cottonwood, aspen, basswood, and buckeye collectively furnish about 7 per cent of the total lumber used for boxes and crates. These four woods are light colored, fairly straight grained, and without very marked odor or taste, except for the basswood, which has a characteristic odor. The annual rings are not clearly defined, and there is no pronounced difference in color between the sapwood and heartwood in any of these species except basswood, in which the heartwood may have a cream-brown color. Basswood may also show black or brownish spots or streaks. Aspen

[9] Douglas fir, a Group 2 wood, is not a true fir.

and cottonwood generally grow rapidly. The aspen, however, commonly develops heart rot as it grows older and is, therefore, often cut when small. The cottonwood, in contrast, often grows to a large size and is generally solid to the center. Its logs therefore make good veneer. Cottonwood resembles in appearence tupelo gum, a Group 3 wood, but is usually lighter in both weight and color and has a coarser texture. The aspens, cottonwoods, basswoods, and yellow buckeye are relatively easy to dry and to work. The cottonwood, willow, and basswood are especially resistant to splitting in driving nails. Cottonwood is used extensively for egg cases.

Magnolia, cucumber (hardwood, southern, and eastern portion of northern forests).
Magnolia, evergreen (hardwood, and southern forests).
Poplar, yellow (hardwood, southern, and eastern portion of northern forests).

These three species of the Group 1 hardwoods just named grow in mixed stands and frequently together. The wood of any one of the three is very difficult to distinguish from that of the others. Both magnolias average somewhat higher in weight and in strength than the yellow poplar. They have about the same strength properties as the average for the Group 3 woods, but they usually split less at the nails. The strength properties of yellow poplar are near the lower limit of the Group 3 woods. Yellow poplar has less nail-holding power and less tendency to split at the nails than the Group 3 woods. It is assigned to Group 1 because it will take the larger nails that are used with Group 1 woods and will consequently make a better box than if it is used as a Group 3 wood. The wood cut from comparatively young yellow poplar trees is white in appearance and is sometimes sold as white poplar. This wood is comparatively hard and tough, and is often confused with basswood or with tupelo gum, a Group 3 wood. Evergreen magnolia and cucumber magnolia also take the Group 1 nailing. Because of the difficulty of distinguishing these woods from yellow poplar, they, too, are placed in Group 1. These woods are of fine texture, are straight grained, and without marked odor or taste. The heartwood, like that of yellow poplar, varies from light to moderately dark yellowish or olive brown with a greenish tinge and sometimes has a purplish tinge or streaks. The annual rings are bordered by light-colored lines. These species are easy to dry and easy to work. The wood cut from old yellow poplar trees holds its shape after drying better than most other woods, whereas the magnolias warp somewhat with changes in moisture content.

Chestnut (hardwood, southern, and eastern portion of northern forests).
Butternut (northern and hardwood forests).

Chestnut and butternut are somewhat similar in color, but are easily distinguished by the broad band of porous spring wood that is present in the annual rings of the chestnut. The wood of both species is moderately light and is usually straight grained. Butternut resembles black walnut in structure but is lighter in weight, softer, and lighter colored, somewhat resembling in appearance black ash, a Group 3 wood. It is without marked odor or taste. The heartwood of chestnut is grayish brown, and has a slightly astringent taste. Chestnut ordinarily has a very narrow band of sapwood, and consequently the lumber is for the most part heartwood. The butternut and chestnut have small shrinkage and ordinarily warp only slightly if at all. These species are in great demand for furniture backing and other uses in which low shrinkage is important. Only small quantities of the lowest grades of butternut are used for boxes and crates.

The chestnut trees are being exterminated by a fungus known as "chestnut blight," which attacks the bark. If the lumber from a blight-killed tree is used before it begins to deteriorate on account of checking, insect injury, and decay, it is as strong as, and for practically all purposes as good as, that from healthy living chestnut. Chestnut trees, however, are very susceptible to attack by insects *(7)*. Pin-hole worms bore into the tree but do not kill it. The stock sawed from such trees produces lumber of a grade known as "sound wormy chestnut."

GROUP 2

The species included in Group 2 are as follows:

COMMON NAME

Fir, Douglas.	Pine, loblolly.	Pine, pond.
Hemlock, eastern.	Pine, longleaf.	Pine, shortleaf.
Hemlock, western.	Pine, mountain.	Pine, slash.
Larch, western.	Pine, pitch.	Tamarack.

The Group 2 woods constitute about 28 per cent of the total lumber used for boxes and crates. Of this amount, about 70 per cent comes from the southern yellow pines, of which there are several species. The southern yellow pines are among the leading woods used for heavy crating and are also used both as rotary-cut veneer and sawed lumber for boxes.

The Group 2 woods are further classified into the following small groups in order to make their description more effective:

Loblolly pine (southern forest).
Longleaf pine (southern forest).
Pitch pine (hardwood and northern forests).
Shortleaf pine (southern and hardwood forests).
Slash pine (southern forest).

The southern yellow pines enumerated above are usually heavier, harder, more resinous, and contain a wider and harder layer of summer wood than the white pines. Wood cut in the Atlantic coast region from loblolly and shortleaf pines and second-growth pine trees of other species is often termed "North Carolina pine," and the shortleaf pine in Arkansas is termed "Arkansas pine." The lumber of these woods is frequently softer and has wider sapwood than true longleaf and slash pines, which average the heaviest and hardest of the pines. Some of the hardest lumber from these species, however, may closely resemble longleaf pine in appearance and properties. The southern yellow pines, although similar in appearance, vary greatly in density and in strength properties both among species and among individual pieces of the same species. Although different types of southern yellow pine lumber are recognized in the lumber trade, it is impossible to distinguish accurately among the species after the logs have been worked into lumber. Because of the wide variation in the properties of southern yellow pine, the selection for boxes should be based upon the specific gravity or density of the wood rather than upon the species.

The southern yellow pines and Douglas fir are somewhat similar in appearance and properties, but Douglas fir usually has a distinct reddish hue and the resin ducts scattered through the wood are less prominent. The dense material of both the southern yellow pines and the Douglas fir splits badly at the nails, and the nails have a tendency to follow the softer wood between the hard bands of summer wood, often running out at the sides of the board, but the lightweight soft pieces nail almost as easily as some of the Group 1 woods. This dense material is stronger and holds nails better than the lighter-weight stock, consequently smaller nails should be used. The same nail-holding power is thus obtained, and the tendency to split or run out is reduced. The dense material is well suited for crate skids and other members in which a high degree of strength is required.

Douglas fir (Rocky Mountain and Pacific forests).

Douglas fir is the most important commercial species of the Pacific Northwest. The stands of Douglas fir exceed in volume those of any other species in the United States. The amount of Douglas fir cut in 1925 was exceeded only by that of the southern yellow pines, which was cut from the several species. Douglas fir is now less important as a box wood than southern yellow pine, mainly because, owing to its region of growth, it has to compete with readily available species that are softer and have less tendency to split at the nails, such as western yellow pine, spruce, and western hemlock.

Douglas fir is not a true fir, spruce, or pine, but belongs to a different genus, one as distinct from the others as the spruces and the pines are distinct from each other. However, it has the same general structure as the other coniferous woods. Its wood differs from the true firs in that it is more resinous, heavier, stronger, and has a darker heartwood and denser summer wood. Douglas fir resembles the southern yellow pines in strength properties and in tendency to split at the nails. Like the southern yellow pines, it is decidedly variable in density and has corresponding variations in strength properties. The Rocky Mountain type of Douglas fir differs in its properties from the Pacific coast type almost as markedly as if the two were different species of trees. The Rocky Mountain type is a short, branchy tree and yields lighter and weaker lumber than the Pacific coast type. Douglas fir when dry is practically tasteless and odorless. It is reported that it is unsuitable for apple boxes because of a scald that is produced on fruits with which Douglas fir comes in contact (*6*).

Hemlock, eastern (northern and hardwood forests).
Hemlock, western (upper halves of Rocky Mountain and Pacific forests).

The woods from these species are similar in general appearance but differ considerably in a number of strength properties. The species resemble the true firs in appearance, but there is no sharp distinction in color between the spring wood and summer wood; the two colors, which are closely similar gradually merge into each other. There also is little difference in color in the hemlocks between sapwood and heartwood, although the latter may have a somewhat pale-brown or reddish hue. The western hemlock is somewhat heavier and stronger than the eastern hemlock, is less subject to shakes and checks, has higher nail-holding power, and has less tendency to split in nailing. In addition western hemlock is cut from large trees, which make it possible to obtain box parts of single-piece stock. When fresh, hemlock has a characteristic sour odor, but this disappears when the wood is dry. The western hemlock is a satisfactory wood for butter containers and is also much used for fresh fruits and vegetables. One-fourth of all western hemlock cut goes into boxes, furnishing about 8½ per cent of all softwood used for this purpose.

Larch, western (upper halves of Rocky Mountain and Pacific forests).
Tamarack (northern forest).

Larch lumber is obtained from two species, the tamarack, growing in the Eastern States, and the western larch, growing in the Western States. The heartwood of tamarack has a russet color, while that of western larch sometimes also has a reddish-brown tinge; both vary from a coarse to a fine, even straight grain. The annual growth rings in western larch are narrower and more nearly uniform in width than in tamarack, and consequently less difficulty is experienced in nailing western larch. The annual rings are marked by a distinct band of summer wood. The butt logs of western larch are often shaky and contain large amounts of gum. This material, however, is usually left in the woods. Western larch and tamarack are not considered suitable for food containers but are quite satisfactory for crates or heavy boxes in which strength is important.

GROUPS 3 AND 4

The Groups 3 and 4 woods, all of which are from hardwood species, are, for convenience, discussed together. The following are the species included:

Group 3

COMMON NAME

Ash, black.	Gum, black.	Maple, silver.
Ash, pumpkin.	Gum, red.	Sycamore.
Elm, American.	Gum, tupelo.	

Group 4

COMMON NAME

Ash, green	Elm, rock.	Maple, sugar.
Ash, white.	Elm, slippery.	Oaks, red.
Beech.	Hackberry.	Oaks, white.
Birch, sweet.	Hickory.	
Birch, yellow.	Maple, black.	

For descriptive purposes the Group 3 and Group 4 woods are subdivided into small groups as follows:

Black ash (northern and hardwood forests).
Green ash (northern, hardwood, southern, and Rocky Mountain forests).
Pumpkin ash (hardwood and southern forests).
White ash (northern, hardwood, and southern forests).

The white and the green ash are Group 4 woods. The black ash and the pumpkin ash are Group 3 woods. Black ash has about the same bending strength as pumpkin ash but is much tougher. The heartwood of white ash and of green ash is a light grayish brown in color, sometimes with a reddish tinge. The heartwood of black ash is somewhat darker; hence its name. The sapwood of all four species is white. In the white and the green ashes it is several inches wide as a rule, although in black ash rarely over 1 inch. The ashes are without marked odor or taste. The woods of the white and of the green ash are very much alike in appearance and strength properties, and are sold as white ash or ash. The lighter-weight grades of white ash and of green ash are commercially classed and sold as pumpkin ash.

Beech (northern, southern, and hardwood forests).
Birch, sweet (northern, hardwood, and southern forests).
Birch, yellow (northern and hardwood forests).

The woods of the birches resemble the beech and the hard maples in appearance and in strength properties. The wood is heavy, fairly straight grained, and without characteristic odor or taste. Birch has more cross grain than maple and does not hold its shape so well. Beech usually produces lower-grade lumber than birch or maple. It is cross-grained, difficult to season, and warps and checks excessively.

American elm (northern, hardwood, and southern forests).
Rock elm (northern and hardwood forests).
Slippery elm (northern, hardwood, and southern forests).

The woods of the several elms are very similar in appearance but differ considerably in weight and in strength properties. The elms have a brownish heartwood tinged with red. The sapwood is white. American elm is a Group 3 wood, whereas rock elm and slippery elm are Group 4 woods. All the elms are without marked odor or taste. Rock elm and slippery elm are heavier than American elm and have correspondingly higher strength properties. The elms have excellent shock-resisting capacity and nail-holding power and are exceptionally free from splitting with nailing. They are especially good for containers that are to be used a number of times. All the elms are difficult to dry and to work. They dress smoothly, but often fuzz and become ragged when steamed or placed in hot water and then subjected to rough handling as are, for instance, milk-bottle boxes. The elms make good veneers for cheese boxes. The elms, however, warp more with changes in moisture content than many other species.

Black gum (hardwood, southern, and eastern half of northern forests).
Red gum (hardwood, southern, and lower eastern portion of northern forests).
Tupelo gum (southern and lower portion of hardwood forests).

Red gum is the principal container wood of Group 3. Before the World War more than 50 per cent of the total amount of red-gum lumber used in the United States went into box construction. Although the demand for red-gum for furniture has probably reduced this proportion, probably 10 per cent of the total quantity of box lumber is red gum (including sap gum). It is the leading veneer wood used in wire-bound and plywood boxes. The wood of the red gum trees may vary from nearly all red wood to nearly all white wood. The red-gum lumber that is cut from the white sapwood of the tree is termed commercially "sap" gum and that which is cut from the reddish-brown heartwood is termed "red" gum. The sapwood is often blued by sap stain. It is difficult to distinguish tupelo gum and black gum from the sapwood of red gum. The wood usually has interlocked grain and is of such uniform structure that the annual rings are inconspicuous. The gums are difficult to dry but may be worked with considerable ease. The strength properties of material from the upper parts of tupelo gum trees are very similar to those of red gum; the wood from the swelled butt, however, is often light and spongy, low in strength, and does not hold nails securely. Light, spongy wood should be excluded from the ends and cleats of boxes and when used for sides, top, and bottom should be used in the thicknesses required for Group 1 woods. All the gums are practically tasteless and odorless and are so similar in strength properties that there is little need to differentiate one from the other.

Hackberry (northern, hardwood, and southern forests).

Hackberry is not plentiful, but its range of growth is extensive. It grows with the ashes and the elms and in appearance bears so close a resemblance to them that it is seldom sold separately. The wood of hackberry is moderately heavy and is generally straight grained. The heartwood is light gray, tinged with green, which distinguishes it from the elms. It is without characteristic odor or taste. Hackberry is approximately the equal of ash for boxes and crates but is slightly inferior to rock elm.

Hickory (southern and southern portion of northern forests).

Small quantities of hickory are mixed with other species and used for boxes and crates. The heartwood is reddish brown, often with darker streaks. The sapwood, which is from one to several inches wide, is white. Hickory is very heavy and hard, has excellent shock-resisting capacity, and is classed as a Group 4 wood.

Black maple (northern and hardwood forests).
Silver maple (northern, hardwood, and western portion of southern forests).
Sugar maple (northern, hardwood, and southern forests).

There are a number of maples, the most important of which are the sugar maple and the silver maple, often known respectively as the hard and the soft maples. The wood of sugar maple is heavy, hard, of uniform texture, and difficult to drive nails into and to cut across the grain. The hard maples are classed as Group 4 woods. The softer maples are lighter in weight and have correspondingly lower strength properties and lower nail-holding power than the hard maples; the softer maples also have less tendency to split and are easier to nail. They are classified as Group 3 woods. The sapwood is white in all maples, and the heartwood is light-reddish brown. The maples are without characteristic odor or taste. They wear smoothly and for this reason are excellent woods for milk-bottle boxes, which are exposed to hot water or steam in sterilizing the bottles.

Red oak group (northern, hardwood, and southern forests).
White oak group (northern, hardwood, and southern forests).

The oaks are heavy, hard, and when dry are without characteristic odor or taste. The annual rings are very distinct in both the white and the red oaks. The most characteristic feature of all oak woods is the broad wood rays, which are very conspicuous as light-colored lines on the end surface of oak lumber and appear on the radial surface as silvery patches. The size and distribution of the large rays distinguishes the oaks from all other woods. The oaks are among the most difficult species to dry without degrade. They furnish but small quantities of lumber for boxes and crates.

No distinction need be made between the various red oaks and white oaks unless they are to be used for containers carrying liquids, in which event the white oaks are preferable, owing to their imperviousness.

Both groups are heavy and hard, and have excellent nail-holding power but split rather easily when nailed. The oaks when dry stay in place well and change slowly in shape with changes in moisture content. The oaks produce excellent rotary-cut veneer and are at times used in combination with gum and ash for wire-bound boxes.

Sycamore (northern, hardwood, and southern forests).

Sycamore is easily identified by means of its conspicuous rays and interlocked grain. Sycamore is quite similar in strength properties to the gums and is often sold mixed with them. It resembles beech and maple in appearance but is lighter in weight and its rays are more conspicuous. Sycamore trees in large sizes are subject to ring shake. The heartwood is reddish brown and the sapwood is somewhat lighter in color. It is the favorite wood for plug-tobacco boxes.

APPENDIX C. SEASONING OF BOX LUMBER

Except for the rotary-cut stock used in plywood and wire-bound construction, boxes are for the most part made from the lower grades of lumber and hence furnish an outlet for large quantities of such stock. Heretofore, a large proportion of the lumber for boxes has been seasoned by air drying. The use of kiln-dried stock, however, is increasing and will probably continue to increase. The lower grades of lumber are low in monetary value so that in kiln drying them the objective is usually to get the moisture out at as low a cost as possible, considering both the expense of drying and the loss through degrade brought about by such defects as checking, warping, and loosening of knots.

It is likely to be assumed that as long as no visible damage results from kiln drying, the strength properties of the lumber are not affected. Throughout this bulletin emphasis is placed on the fact that ordinarily the strength of a box is limited by the fastening resistance of the wood, including resistance to pulling of the fastenings and to breaking at the fastenings. In the development of specifications and schedules for the kiln drying of wood for airplane construction (27), thousands of tests were made of the effect of different kiln-drying schedules on the bending strength, shock resistance, and other properties important in airplane parts. These tests demonstrated that wood can be kiln dried without loss in any strength property as compared to air drying under optimum conditions. They also demonstrated that the various strength properties and the individual species differ greatly with respect to their sensitiveness to the higher temperatures sometimes used in kiln drying and that stock may be very seriously damaged in strength properties without showing any visible evidence of this damage. The property most sensitive to kiln drying is shock resistance, which in some species is seriously reduced by comparatively low temperatures and very greatly reduced by the higher temperatures frequently used in kiln drying lumber. In every instance in which boxes made from lumber known to have been subjected to extremely high temperatures have been tested they have been found to be very low in resistance to rough handling as compared to boxes made from air-dry lumber. This was shown by the early occurrence of the failures that resulted from the breakage of boards at and near the fastenings. Fastening resistance is reduced by any influence that renders the wood fibers brash or brittle. The low shock resistance in the airplane woods tested resulted from the high temperatures in kiln drying, which produced brashness. This fact demonstrates that care should be exercised with respect to the temperatures employed in the kiln drying of box lumber. As a result of the tests of the effect of kiln drying on airplane woods, drying schedules [10] by means of which stock can be kiln dried without material damage to any strength property have been established. Since box boards are thinner than airplane stock the time necessary [11] for them to be exposed to the kiln temperature is shorter. Consequently higher temperatures than those allowed by the airplane schedules can no doubt be employed in drying material for use in box construction without reducing the strength and serviceability of the boxes. Unfortunately the maximum temperatures that can be safely used are not known.

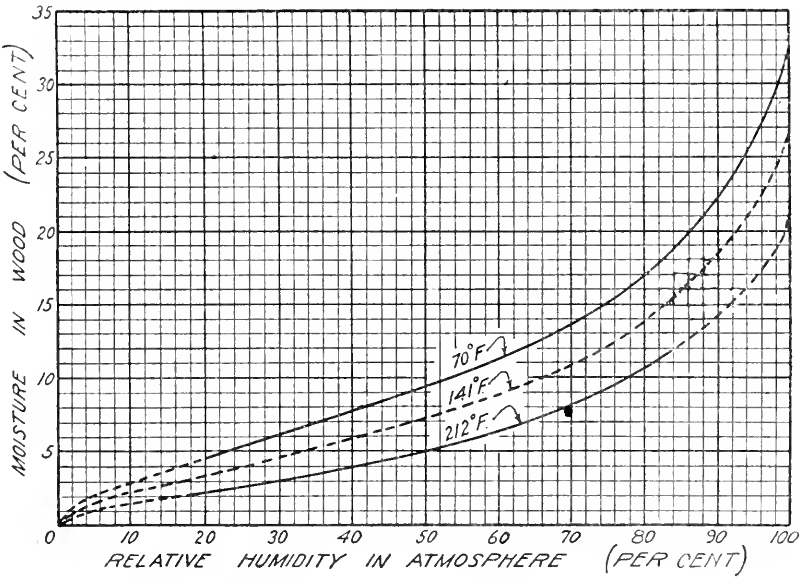


FIGURE 25.—Effect of relative humidity and temperature on the equilibrium moisture content of wood

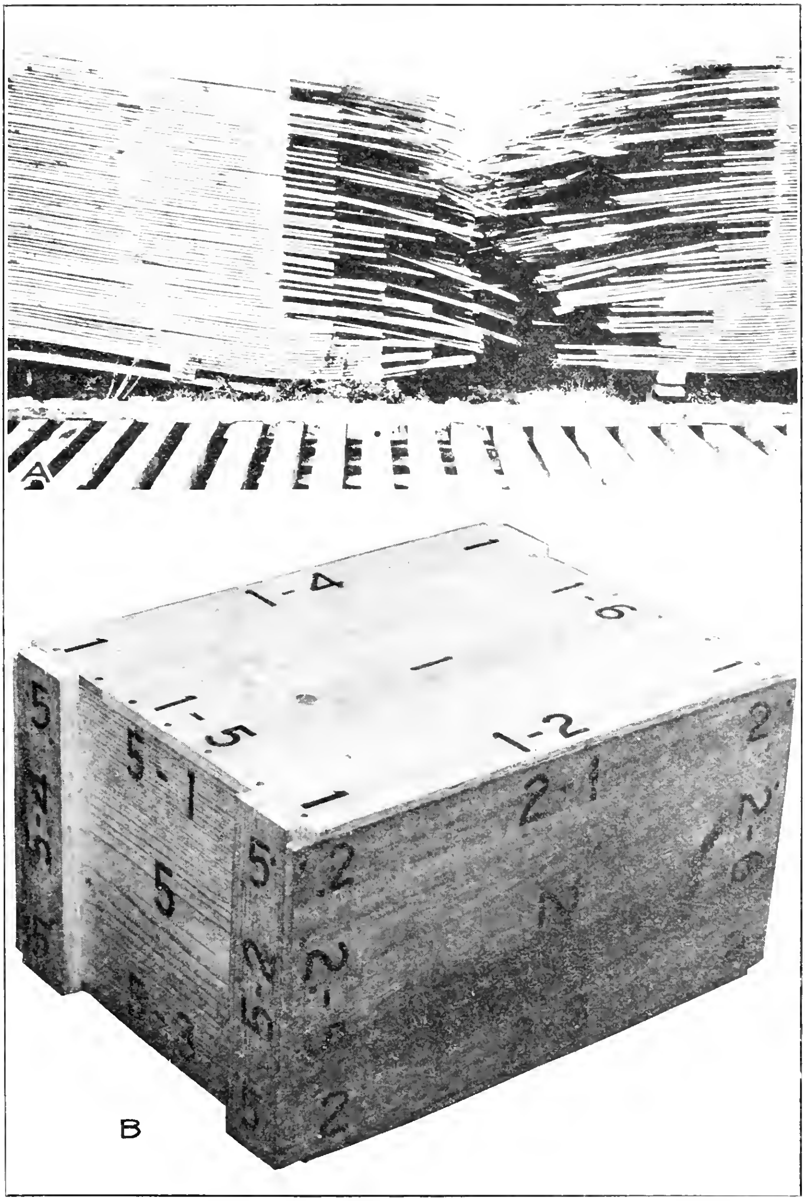
It is impossible, therefore, to offer definite recommendations as to maximum permissible temperatures. It does, however, seem advisable to raise the caution that the temperatures frequently used in kiln drying such stock may result in very serious damage and to recommend that particular care be given to the drying of box lumber. If minimum thicknesses are to be used in boxes, it is essential that lumber be dried without damage to its strength properties.

Even when conditions are carefully controlled to avoid permanent damage it is undesirable that box lumber be kiln dried to too low a moisture content. Lumber that is overdried, until it has regained a normal moisture content through reabsorption, is quite brash and therefore subject to damage in handling, machining, and nailing. If lumber in the very dry condition is nailed, the nails will lose much of their holding power when reabsorption occurs under exposure to normal atmospheric conditions. Experience indicates that there is no advantage in drying box lumber below the average air-dry condition, which is usually about 12 to 15 per cent moisture content.

In the following pages are given suggestions for seasoning by both air drying and kiln drying. More detailed information on types of kilns and their control

[10] These together with other schedules for the kiln drying of wood of different species are presented in Kiln Drying Handbook (21). Maximum kiln temperatures permitted by the airplane schedules vary from 105° to 145° F. depending on the species to be dried and on the stage of the drying.

[11] The experiments in drying airplane woods were for the most part of 8/4-inch stock.



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A, Poor piling for air seasoning; B, method of marking boxes and crates for test

and operation and on air seasoning may be obtained from the Forest Products Laboratory (*21*).

Both the equilibrium moisture content and the rate of drying of wood are dependent upon the humidity and the temperature of the surrounding air. When wood is subjected to a constant relative humidity and temperature, it will in time come to a definite moisture content, which is called the equilibrium moisture content. The relationship between the equilibrium moisture in the wood, the temperature, and the relative humidity of the surrounding atmosphere is shown in Figure 25. From the chart it may be seen that the moisture content increases with increase in relative humidity, but decreases with increase in temperature. Since temperatures are lower and humidities are higher in winter than in summer, wood stored outside reaches a higher moisture content in winter than in summer, but when stored in a heated room wood becomes drier as a result of the lower relative humidity in the room.

GEOGRAPHIC VARIATIONS IN HUMIDITY AND TEMPERATURE

In addition to seasonal variations in humidity and temperature, there are also variations from part to part of the United States. Table 10 shows the relative humidities at different seasons of the year for a number of widely separated cities. The humidities are based on daytime readings made by the United States Weather Bureau and do not give the mean average humidity for 24-hour periods. The humidity during the night is usually much higher than that during the day, and since the equilibrium moisture content will follow the mean average humidity for the 24-hour period, it will be somewhat higher than the moisture content indicated in the table.

TABLE 10.—*Relative humidities at different seasons in various parts of the United States*

Locality	Mean relative humidity in per cent based on daytime readings in—			
	Winter	Spring	Summer	Fall
New York City	73	70	74	75
Cleveland, Ohio	77	72	70	74
Spokane, Wash	82	61	47	67
Seattle, Wash	83	73	69	81
Phoenix, Ariz	47	32	32	41
San Diego, Calif	74	78	81	78
San Francisco, Calif	79	79	84	80
Denver, Colo	54	51	49	46
Washington, D. C	72	69	75	76
El Paso, Tex	45	27	41	46
Galveston, Tex	84	82	79	78
Jacksonville, Fla	80	74	80	83

AIR SEASONING

The small amount of additional work required to pile lumber properly for air seasoning (*21*) so as to shorten the time required for drying and to reduce deterioration is usually well worth while. Lumber thrown in a pile promiscuously, improperly stickered, or piled with loose projecting ends or on uneven foundations will warp, check, split, and otherwise depreciate in value in a comparatively short time. (Pl. 32, A). In order to be considered properly air seasoned lumber should be of a uniform moisture content of the desired percentage, straight, free from stain and decay, without undue damage to knots, and without surface checks. Observance of the following suggestions will help to secure these results:

A. Foundations:
1. The foundation should be rigid and level in one direction.
2. The foundation should slope from front to rear about 1 inch to the foot.
3. The foundation should be high enough from the ground and sufficiently open to allow good circulation. The lumber should be at least 18 inches from the ground.
4. Material for foundation piers is listed in the order of durability: Concrete or masonry. Pressure creosoted blocks of any species or the heartwood of cypress, redwood, or cedar. (When untreated woods are used, all points of contact should be given two coats of hot creosote.)
5. Stringers and beams should preferably be of steel or of pressure-creosoted timbers. Untreated durable woods with two coats of hot creosote at points of contact may be used.

B. Air flues:
1. Even-width stock should have lateral spaces between adjacent boards not less than 20 per cent of the width of the board. The boards in each succeeding tier should be placed directly over those below so that the lateral spaces between boards will form uninterrupted vertical flues.
2. In uneven-width material the equivalent of one tapering chimney not less than 12 inches wide at the bottom should be used for a 6-foot pile and often two such chimneys in wider piles. The lateral space between adjacent boards should be not less than 1 inch for 4/4-inch stock and 1½ inch for thicker stock.

C. Stickers:
1. All stickers should be sound, free from stain, and of even thickness. All stickers in the same course should be of the same thickness.
2. Each tier of stickers should be aligned and should be supported firmly along the entire length of the sticker.
3. Stickers for 4/4-inch lumber should be not less than seven-eighth inch thick, usually 1½ inches wide for hardwood lumber, and preferably not more than 4 inches wide for any lumber. For thicker lumber, stickers should be 1½ inches thick or perhaps more.
4. Stickers should slightly overlap the ends of the stock in order to reduce end checking.
5. Stickers should be not over 2 feet apart for hardwoods up to 6/4 inch in thickness. For thicker hardwoods and all softwoods three tiers of stickers should be used for 16-foot stock.

D. Placing of lumber:
1. Piles should be erected of boards of equal length, whereve. practicable.
2. Box piling should be used for mixed lengths. With this system the longest stock is piled in the outer tiers, and short lengths within the pile with one end of a board at one end of the pile and one end of the adjacent board at the opposite end of the pile. In each succeeding course, the outside end of each board should be kept immediately over the ends of those below it.
3. Each layer should be composed of boards of the same thickness.
4. The front of the pile should have a forward slope or pitch to the extent of 1 inch for each foot in height.

E. Covering:
1. All material should be under cover, either in an open shed or with roofs over individual piles.
2. A minimum front height for the pile roof of 6 inches above the lumber and a slope rearward of at least 1 inch to the foot should be used.
3. The ends and the sides of the roof should project sufficiently to prevent snow and rain from beating into the lumber piles.

F. Site:
1. The yard should be well drained and kept free from weeds and débris.
2. The space between the sides of adjacent piles should be at least 4 feet wide and the alley between the rears of adjacent pile rows should be at least 8 feet wide.

KILN DRYING

Lumber properly kiln dried *(21)* should be free from surface and end checks, honeycomb, and casehardening, and the stock should be reasonably straight, and the mositure content should be as required in amount and in uniformity. Observance of the following suggestions may help to secure these results:

A. Dry kilns.
1. The construction of the kiln, the control equipment, and the arrangement of heating coils, spray lines, and ventilators must be such that the temperature and humidity may be controlled within reasonable limits.

B. Material:
1. Species of the same drying characteristics may be included in the same kiln charge.
2. Reasonable variation in thickness of stock in the same charge may be permitted if drying conditions are regulated for the wettest, thickest, and slowest drying stock.

C. Piling.
1. The method of piling must be suited to the circulation system of the kiln in which the stock is dried. Two general methods of piling are used: (1) Edge stacking where the stock stands up edgewise in the kiln truck with the edges touching, the faces of the boards separated with vertical stickers, and the circulation intended to be up or down in the open space between the faces of the boards. (2) Flat stacking, where the stock is laid flat in the loading, and spaces are provided between the faces of the boards by means of stickers laid horizontally. Circulation may be principally vertical, or principally horizontal; it always is a combination of both directions.

These two methods of piling are applicable to either natural circulation or forced circulation types of kilns.

In natural-circulation kilns the air movement is generally downward through the load when the stock is relatively green and upward when the stock is nearly dry. In edge stacking the pile provides the vertical flues suited to this air movement. For flat stacking vertical flues should be provided by separating the boards at least 1½ inches. In piles 5 feet or over in width, a vertical flue at least 8 inches wide should also be provided in the middle of the load from the bottom of the pile up to within six layers of the top of the pile.

In forced-circulation kilns the design of the kiln usually determines the method of piling best adapted to the circulation system. The following suggestions should be observed:

1. One-inch stickers should be used for most classes of stock up to 6/4-inch in thickness and 1½-inch stickers for stock thicker than 6/4; for edge-piled stock, requirements of the stacking machine may determine both their width and their thickness. In flat piling the stickers must be in vertical alignment not over 2 feet apart for 6/4-inch stock and not over 3 feet apart for stock thicker than 6/4-inch. Except for edge stacking, all sticker lines should bear solidly on beams or crossties.
2. Each layer should consist of boards of the same thickness.
3. Piling should be done so as to avoid overhanging ends of boards. At least 18 inches should be allowed between the loads and the side walls.
4. Box piling should be used for flat-piled stock of mixed lengths. (See paragraph D2, page 82.)

D. Instruments.

1. At least one recording hygrometer should be used in each kiln. This should be checked at least once in every 30 days against a standard thermometer and set at an accuracy of 1° F.
2. The bulbs should be placed so as to measure the severest drying conditions in the load. Bulbs should be shielded from the direct radiation of hot steam coils, and the effect of cold lumber or kiln walls.
3. Occasional readings should be taken with wet-bulb and dry-bulb hygrometers to determine the accuracy of the recording hygrometers and the variations of temperature and humidity within the kiln.
4. The wet bulbs of all hygrometers should be kept covered with a film of water. If a wick is used it should be changed frequently. If a porous wet bulb is used it should be kept dripping and free from incrustation.

E. Records:

1. Temperature and humidity records should be accurately and systematically kept for each run.

F. Steaming:

1. The lumber may be heated a comparatively short time at some temperature above the drying schedule with a relative humidity that will not cause drying, the purpose of such steaming being to warm the stock, to reduce moisture gradient, or to relieve case hardening.

G. Tests during and after drying:

1. Adequate tests should be made during the drying to insure proper drying and to serve as a guide for regulating temperatures and humidities (*21*).

APPENDIX D. CONTAINER TESTING

Since containers in service are subjected to various and constantly changing transportation hazards, it is impractical to secure complete data for design by observing containers in service. Examinations of failures will reveal the weaknesses and suggest the principles of design to apply in overcoming them, but it is impracticable to make changes and develop balanced construction through service tests alone. For this reason, laboratory tests that closely simulate the hazards of transportation have been developed. Each test is designed to reproduce one or more of the stresses encountered in service. During these tests the sequence of failures can be observed and the weakness from which they result determined.

Since by means of such tests any number of containers can in turn be subjected to exactly the same action, the tests provide a ready means for developing the fundamental principles of design and the relationships of the various details necessary to produce a balanced construction, but, just as service tests can not be used for properly balancing the design, so laboratory tests do not show the minimum requirements of service. Each has a distinct field that can not be assumed by the other. In the following pages there are described a number of the methods that have been devised for subjecting containers to conditions and hazards similar to those encountered in service, for testing features of construction, and for testing container accessories and materials.

The methods, which for the most part have been developed by the Forest Products Laboratory, (*14*) have become standard and are used by container manufacturers and shippers and by commercial laboratories in this country as well as by laboratories in several foreign countries. These tests have been developed to bring out the weaknesses in the common types and designs of containers. As changes are made in container design and in methods of handling packages in shipment, the characteristic hazards and weaknesses of containers will be changed and these tests will probably need revision.

MARKING TEST BOXES AND CRATES

Numbering the faces of the box or crate makes for convenience in recording the test data. The faces are numbered as follows: The top is 1, the right side 2, the bottom 3, the left side 4, the end toward the observer 5, and the opposite end 6. The edges and corners are designated by combinations of these numbers as indicated in Plate 32, B.

DROP-CORNERWISE TEST

In the drop-cornerwise test, the box or crate with its contents is suspended with a pair of diagonally opposite corners in a vertical line and is dropped from a height of 6 inches upon a cast-iron plate or other solid surface, as illustrated in Plate 33, A. The drops are made on the corners in numerical rotation as follows:

Faces meeting	Corner number	Faces meeting	Corner number
5-1-2	1	5-3-4	5
6-3-4	2	6-1-2	6
5-2-3	3	5-1-4	7
6-1-4	4	6-2-3	8

After the container has been dropped on each of the eight corners, the height of drop is usually increased 6 inches and the cycle repeated. Accurate records are made of the nature, the extent, and the sequence of each failure and the test is continued until complete failure occurs.

The drop cornerwise is a very severe test on the ability of the container to withstand shocks and resist distortion. It does not give satisfactory results for improvement of design if the first drops are made from a height that causes complete failure, since several failures may then occur simultaneously, thus making very difficult the determination of the weakness that first developed. Plate 33, B shows the details of the apparatus used for making this test.

DROP-EDGEWISE TEST

The drop-edgewise test (pl. 34, A) is similar to the drop-cornerwise test except that the container is dropped on an edge instead of a corner.

DROP-FLATWISE TEST

In the drop-flatwise test the container is dropped squarely on one of its faces. (Pl. 34, B.) The container may withstand the shock with relative ease, but it usually is a severe test of the packing of fragile articles. The test may be varied by dropping the container successively on one or more of the faces as desired.

DROP-PUNCTURE TEST

The capacity of a box to resist puncturing is often tested by dropping another box cornerwise (pl. 34, C) or by dropping some other pointed object on the face being tested. (Pl. 34, D.)

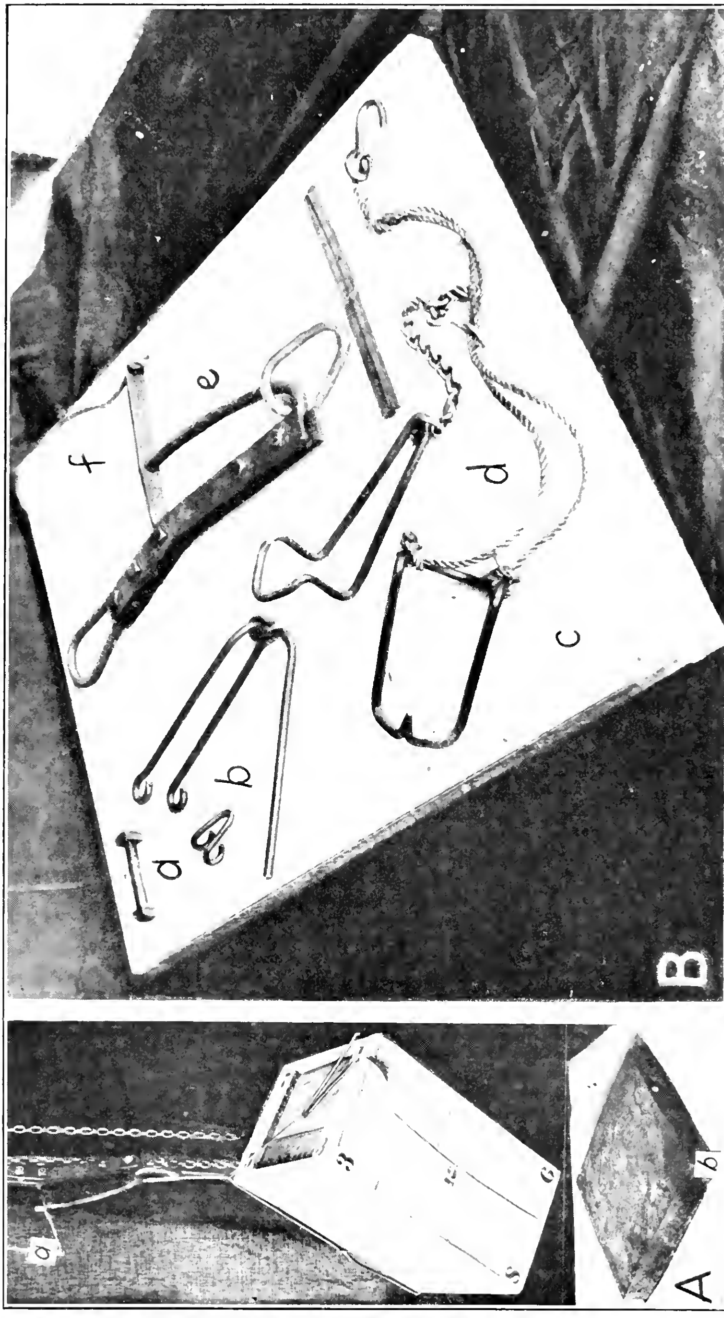
WEAVING TEST

The machine illustrated in Plate 35 is designed to simulate the side swaying or rolling of a moving freight car, or the repeated starting and stopping of a car. The swaying action of a train is reproduced on the testing machine by an oscillating table or car, which can be made to move horizontally forward and backward at different speeds through any distance up to a maximum of 8 inches. The box or crate to be tested is fastened rigidly to the table, by clamps along two of its bottom edges, and a weight equal to the average load carried by a container in the bottom tier of a loaded car is then fastened on the top. When the machine is put in operation the container is carried back and forth with the movement of the table.

This test affords a means of comparing boxes or crates with respect to their rigidity, which is indicated by their resistance to weaving or skewing. The test may be continued until complete failure occurs, but usually the box or crate is tested on the machine until the joints are loosened, and then it is taken to a drum-testing machine.

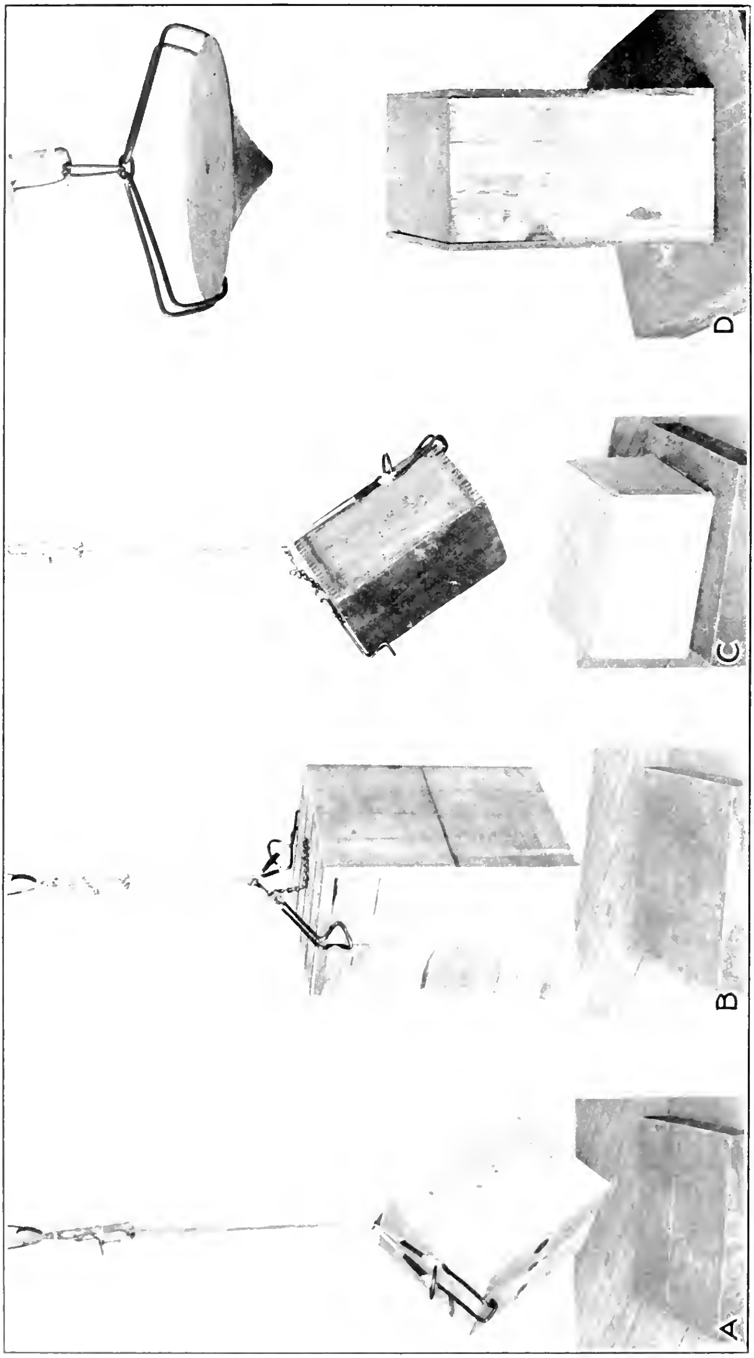
IMPACT-SHEAR TEST

The oscillating table is also used to simulate the starting and stopping action of a freight car, which produces an impact shear in the container. For this test the box is suspended freely and above the table by two metal straps. The supporting straps form a parallelogram suspension and horizontal guides, fitted with rollers to reduce the friction, allow the box to swing only in the direction of its

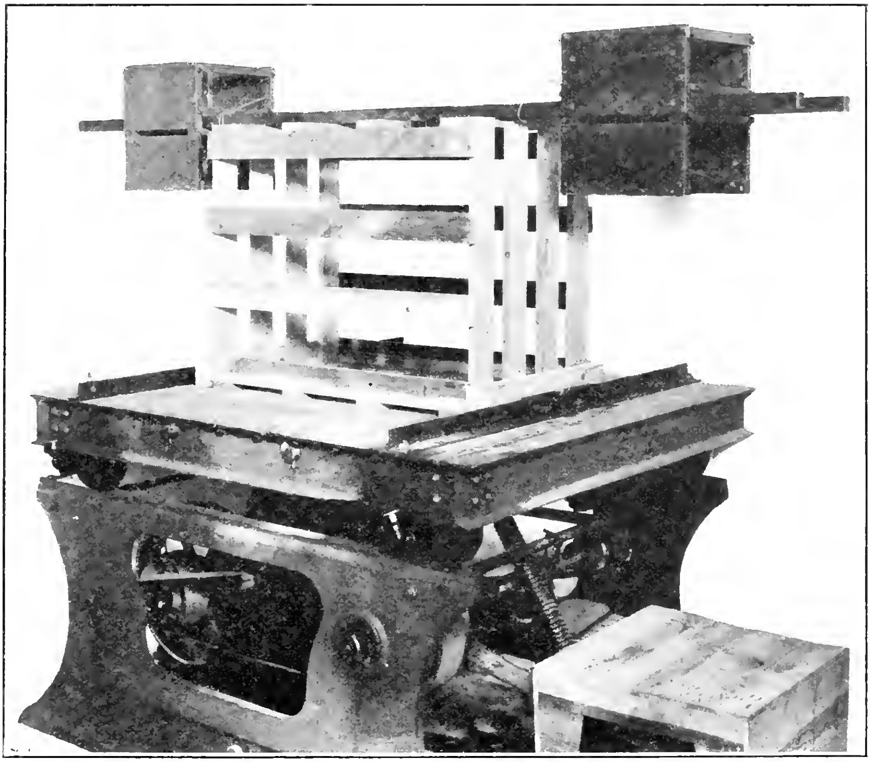


M978F

Drop-cornerwise test: A, (a), releasing device or trip; (b), cast-iron plate; B, details of drop-test apparatus; (a) and (b), parts of releasing device for light packages; (c) and (d), sling for light packages; (e), releasing device for heavy packages; (f), trip rope

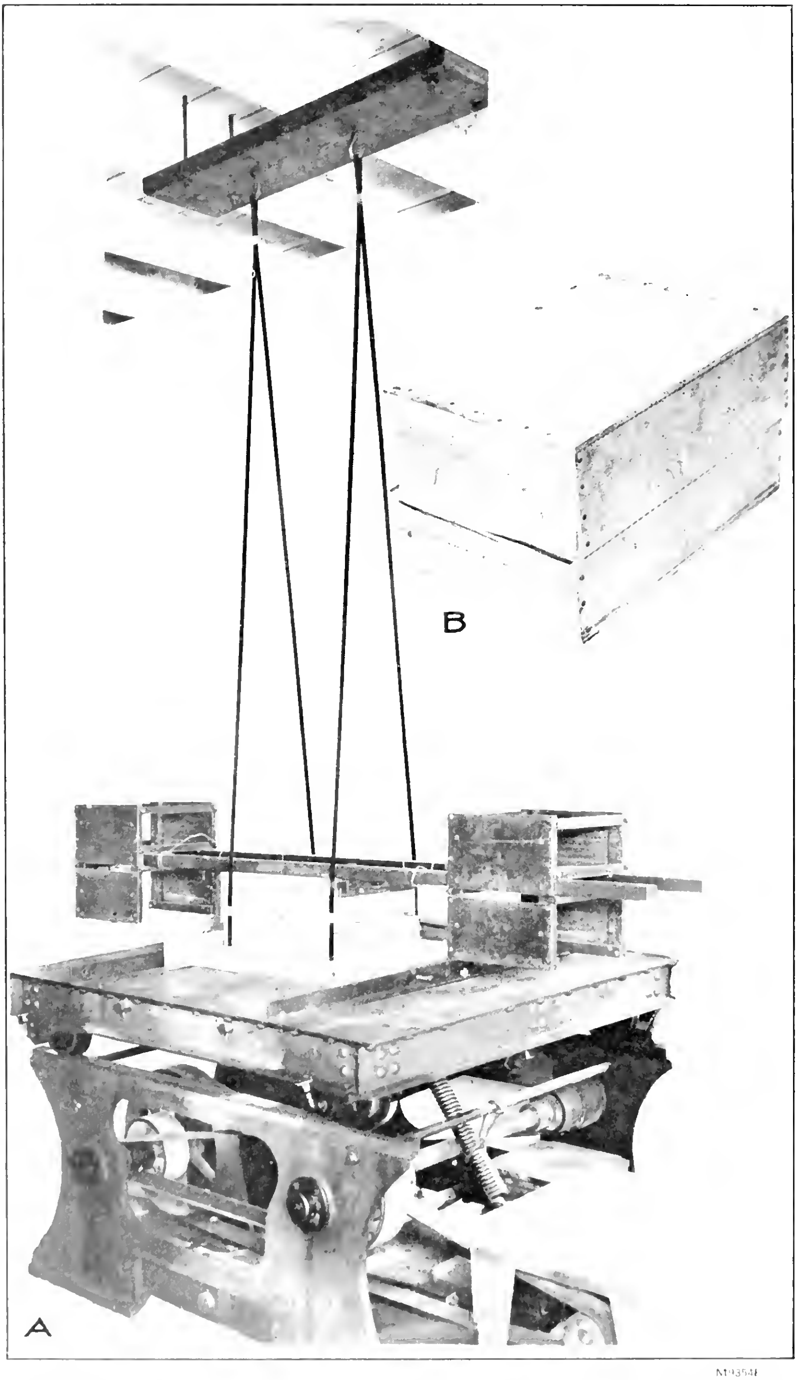


A, Method of making drop-edgewise test; B, method of making drop-flatwise test; C, drop puncture test made by dropping another box cornerwise; D, drop puncture test made by dropping a pointed object



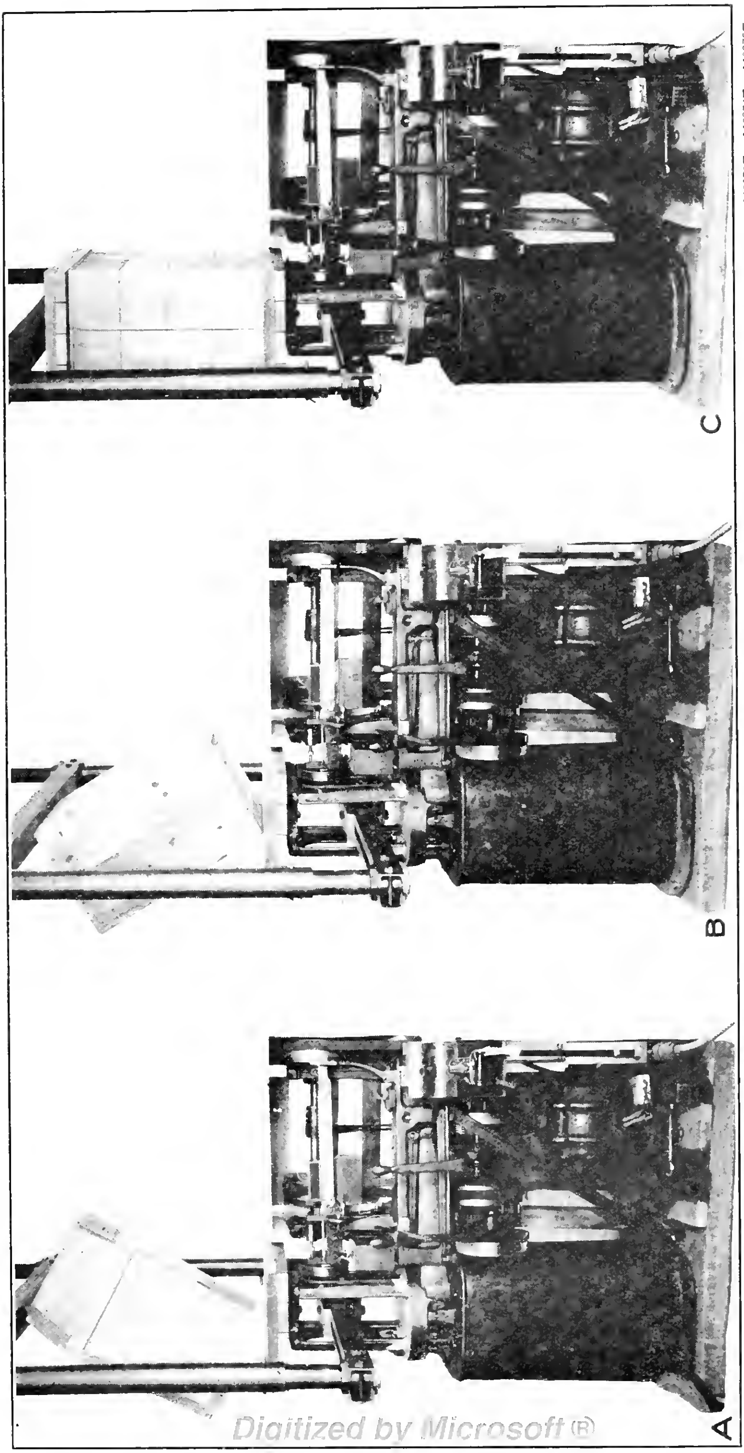
M8971F

WEAVING TEST MACHINE

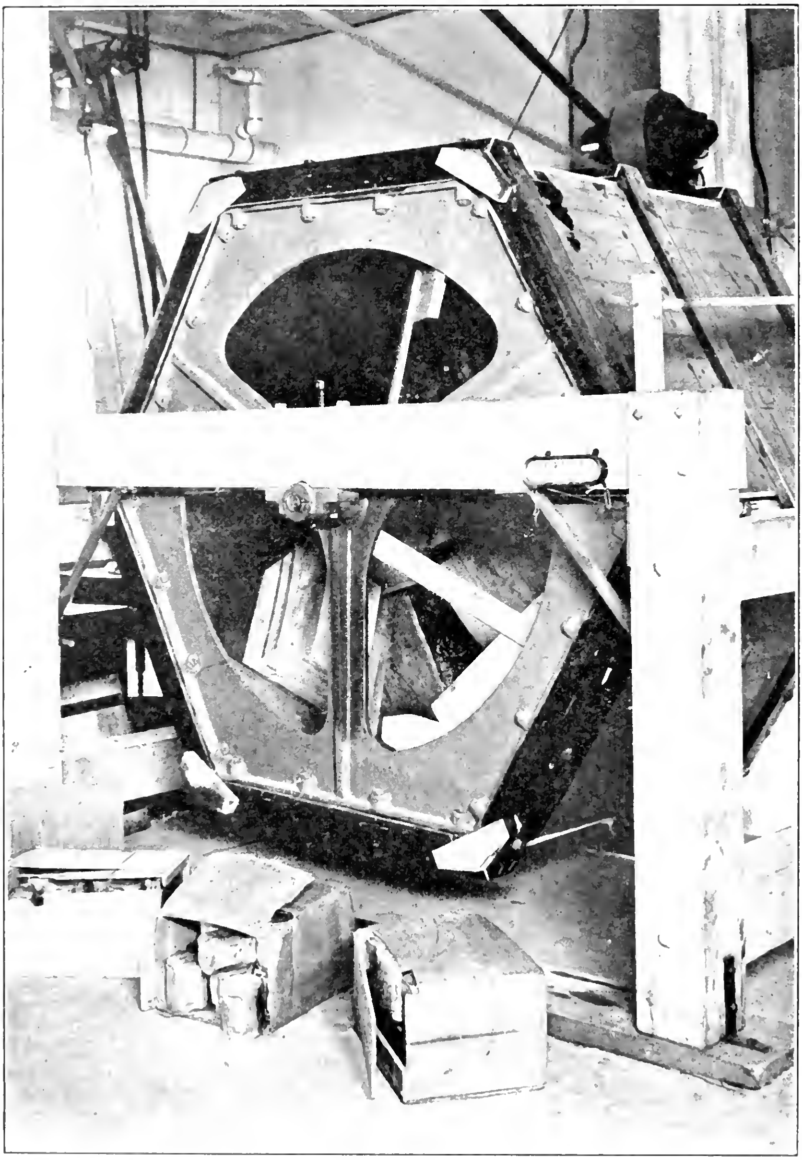


M93548

A, Oscillating table of the weaving test machine adjusted for simulating the starting and stopping action of a freight car; B, box showing type of failure in this test

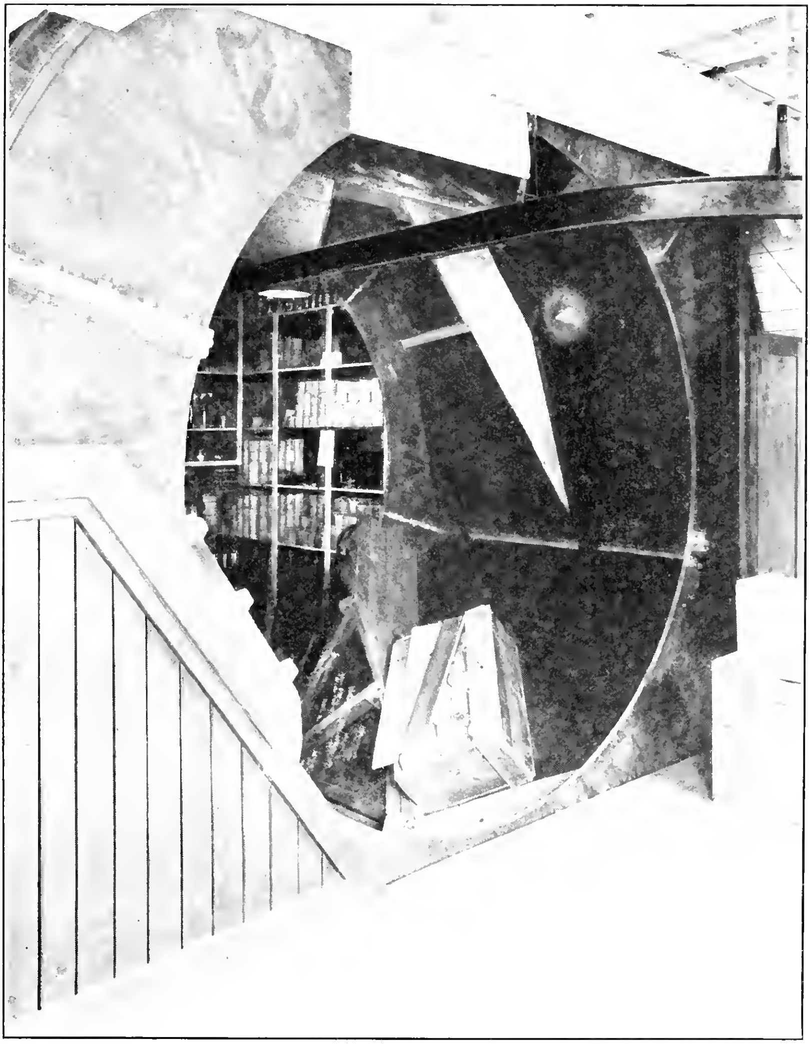


A, Method of making compression-on-corner test; B, method of making compression-on-edge test; C, method of making compression-on-face test



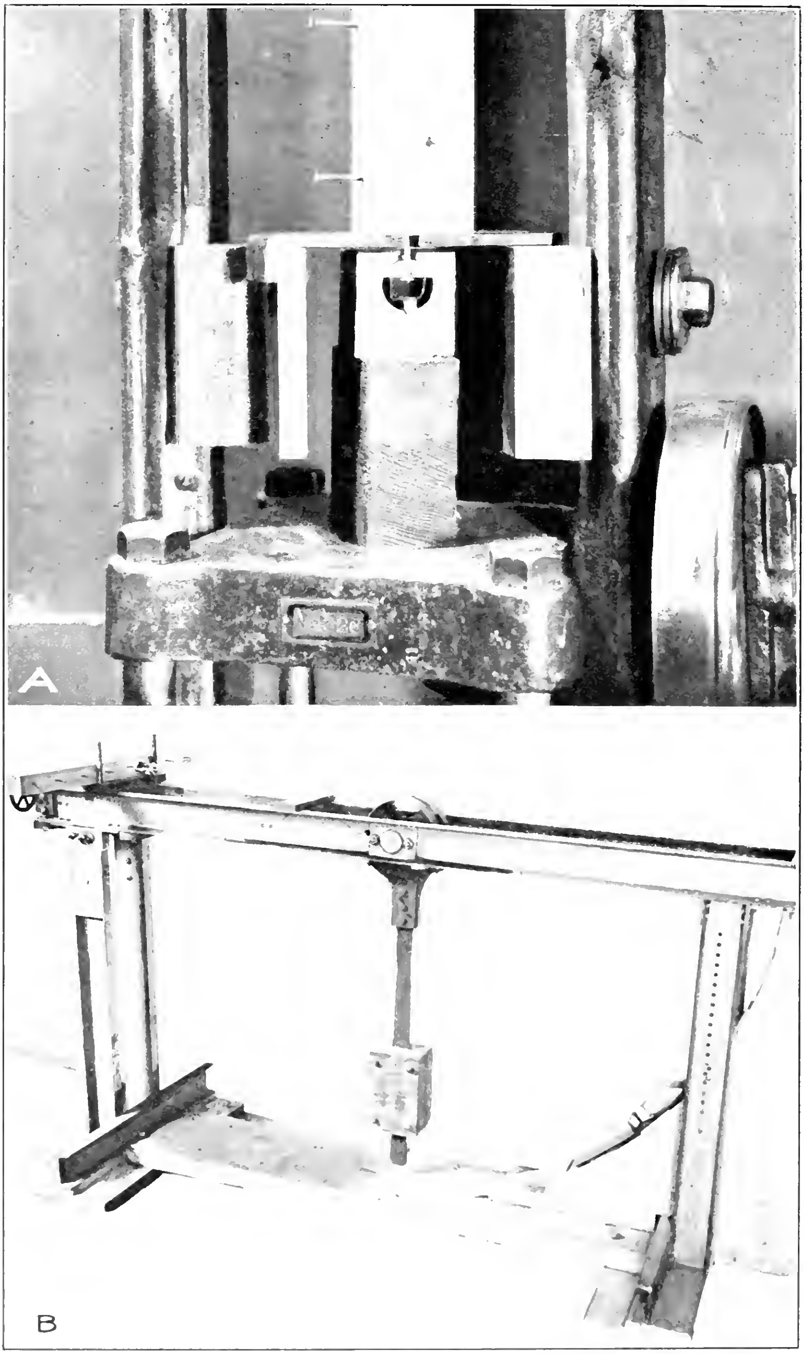
M-?9F

Small revolving hexagonal drum box testing machine. Dimensions, 7 feet inside diameter and 4 feet in width



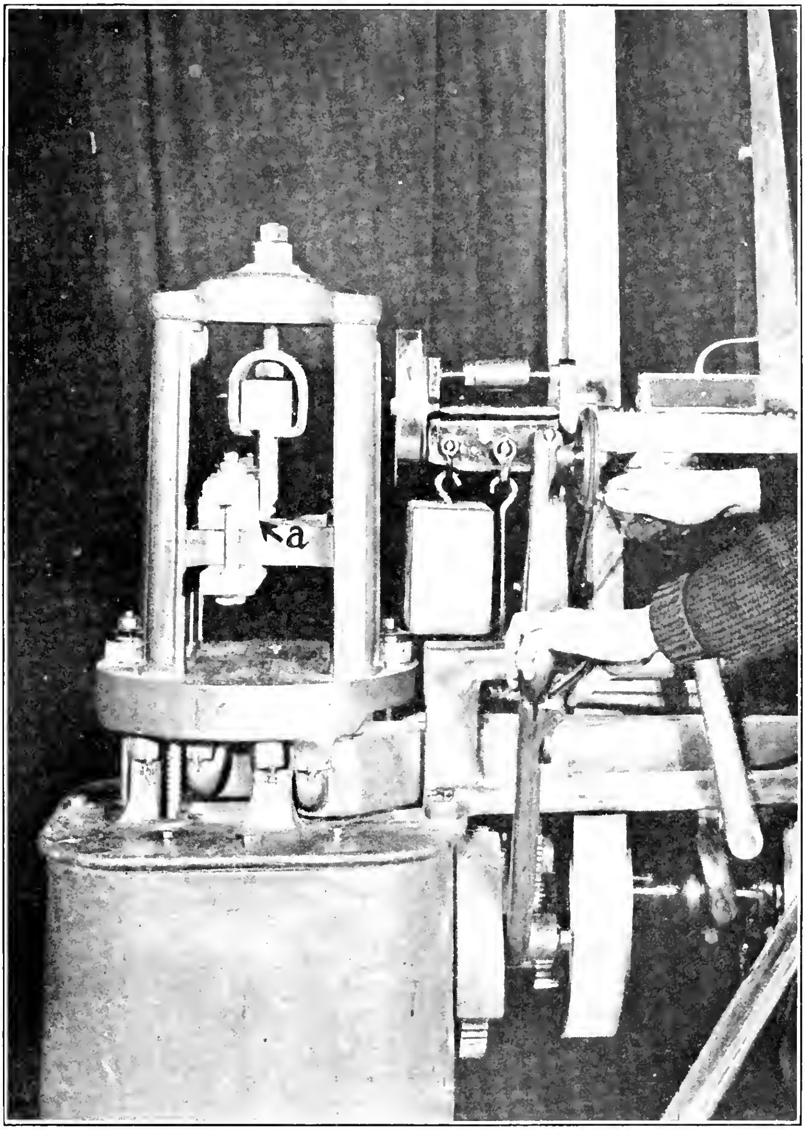
M8972F

Large revolving hexagonal drum box-testing machine. Dimensions, 14 feet inside diameter and 8 feet in width



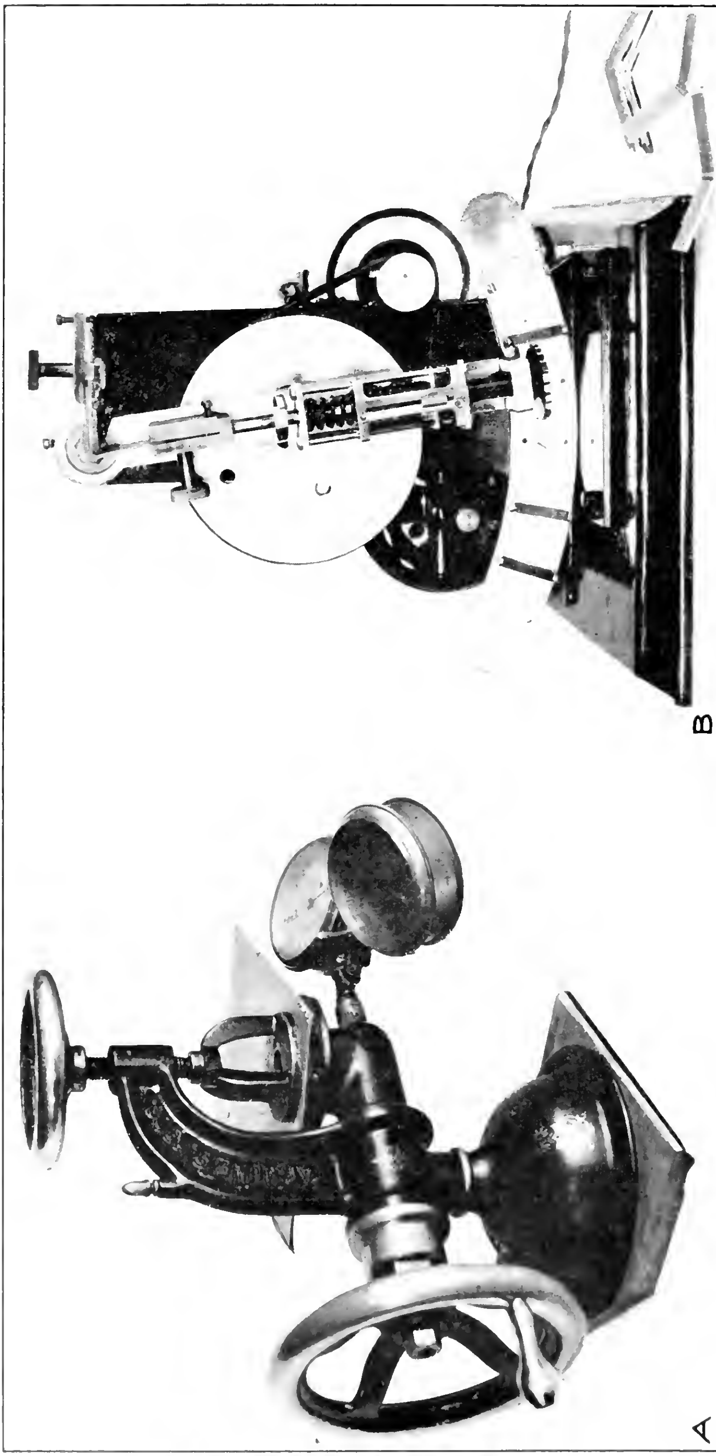
M6819F M9315F

A, Nail pull test with static load; B, pendulum type machine arranged for determining work absorbed in pulling nails



M2400F

Shear test on a nailed joint. (*a*) Test specimen



M9543F M6888F

A, Method of making Mullen test on fiber board; B, Forest Products Laboratory score tester for solid fiber and corrugated board length, which is parallel to the motion of the table. Two stops are fastened securely to the table and the ends of the box strike against them as the table moves forward and backward. Any desired weight may be placed on top of the box during the test. The number of complete oscillations of the table before failure of the box is indicated by an automatic counter. (Pl. 36.)

COMPRESSION-ON-DIAGONAL-CORNERS TEST

The rigidity of a container or its capacity to resist diagonal distortion and twisting is usually determined by measuring the force required to compress the container diagonally. (Pl. 37, A.) The load is measured at each ¼-inch deflection of the container and the test is continued until the container has reached the maximum load that it will support, or has distorted sufficiently to cause damage to the contents. The amount that each face of the container twists out of a plane is also measured for each one-fourth inch of diagonal distortion. This test produces practically the same types of failures in the container as the drop-cornerwise test but at a rate that enables a closer study of the weaknesses.

COMPRESSION-ON-EDGES TEST

The compression-on-edges test is made by applying a compressive force over the whole length of two diagonally opposite edges of a box or crate as illustrated in Plate 37, B. The force required to produce each increment of distortion is measured as in the diagonal compression.

COMPRESSION-ON-FACES TEST

The capacity of a container to resist crushing, such as that which may be caused by heavy static loads in storage warehouses, is measured by applying direct compression over the whole surface of two parallel faces as illustrated in Plate 37, C.

SHEAR TEST ON BOXES

The shear test consists of shearing the box into two parts along a plane, usually parallel to the top and bottom and in the direction of the length. Ordinarily one end of the box is set on a cast-iron plate in such a position that one edge of the box overhangs the plate 2 inches. The load is applied to the opposite end of the overhanging part. Only the maximum load required to cause failure is recorded.

DRUM TEST

The revolving-drum type of box-testing machine (pls. 38 and 39) combines in a single test practically all of the stresses and distortions that containers encounter in service. Upon the six internal faces of the hexagonal drum, hazards and guides are arranged in such a manner that, as the drum revolves, the loaded box or crate slides and falls, striking on its ends, sides, top, bottom, edges, and corners in such ways that the stresses, shocks, and rough handling of actual transportation are simulated. On one face of the drum is a projection upon which the container falls to encounter a puncture hazard similar to that of a box upon which another has dropped cornerwise. The large drum revolves once a minute, thus enabling the observer to note the beginning of any failure and to trace the failures until the container becomes unserviceable.

SUPPLEMENTARY TESTS

In addition to tests on completed containers, various tests are made that give much information of value on the properties of container materials and details of construction. Among the most important of these tests are the following:

MECHANICAL-PROPERTIES TEST

Mechanical-properties tests are made on sawed lumber, rotary-cut lumber, and plywood. Standard methods (*1*) of testing small clear specimens of timber are used. Results of tests on small clear specimens of a considerable number of species are in Table 7 and Appendix F.

The holding power of nails, screws, bolts, and other fastenings or their resistance to direct pull by a static load applied in a direction parallel with the nail shank is usually determined by a special gripping device used with a testing machine as shown in Plate 40, A. In making this test only the maximum load to start is indicated. Figures representing the holding power of nails when driven into the radial, tangential, and end surfaces of different species as determined by this test are given in Table 4.

WORK OF PULLING NAILS

The capacity of nails and other fastenings to resist withdrawal when subjected to shocks is determined by means of a pendulum type of machine, shown in Plate 40, B. The piece containing the nail to be pulled is held against two steel pins. With the pendulum in approximately a vertical position the cable is clamped to the head of the nail. The cable is then slackened as the pendulum is raised until it engages the spring catch, which in turn is adjusted to such a position that when released the pendulum will pull the nail with a single swing. The angle of rise of the pendulum after pulling the nail is read by means of a vernier, which travels on the hub of the pendulum. By computation the work absorbed in pulling the nail can be determined.

SHEAR TEST ON NAILED JOINTS

The resistance of the wood to the nails shearing out at the ends of the boards may be determined as illustrated in Plate 41.

TENSION TESTS

As shown in Plate 40, A, a testing machine intended for standard work can be equipped with special devices for making various other tests; for example, tensile-strength tests on metal strapping and wire ties, tension tests on nailed joints, shear and bending tests on joints held with corrugated fasteners, and tests on special materials and accessories, such as rope, webbing, metal corners, handles, and hinges.

DETERMINATION OF MOISTURE CONTENT

The moisture content of wood may be determined in various ways. The following method is well adapted for box lumber. A section as wide and thick as the original board and 1 inch along the grain is cut at least 2 feet from one end of each of several representative pieces. Immediately after the sample is cut all loose splinters are removed and the sample is weighed on a sensitive scale. This weight is called the "original weight."

The sample is then dried in an oven, in which a uniform temperature of about 212° F. and a free circulation of air over the end grain are maintained, until the weight becomes constant. This usually requires 48 hours. The dry sample is then weighed and the result termed the "oven-dry weight." The time required for drying may be reduced about one-half without great error in the results by using samples one-half inch long.

To calculate the moisture content, the oven-dry weight is subtracted from the original weight and the result divided by the oven-dry weight and multiplied by 100. This gives the percentage of moisture based on the oven-dry weight. The formula is:

$$\frac{(\text{Original weight})-(\text{oven-dry weight})}{\text{oven-dry weight}}\times 100=\text{moisture content in per cent.}$$

If an oven is not available for drying the samples reasonably accurately, moisture determinations accurate to within 1 or 2 per cent may be made by drying them on steam pipes.

BURSTING-STRENGTH TEST OF FIBER BOARD

The bursting strength (*19*) is the standard test used as a basis for specifications for fiber boxes. This test consists essentially in clamping the paper board between two surfaces having concentric circular apertures 1.24 inches in diameter and then applying hydraulic pressure through a noncompressible fluid to a rubber diaphragm secured to one of the circular apertures. The pressure required to burst the board is recorded by means of a pressure gauge calibrated to record pounds per square inch and is reported in points. The Mullen and the Cady tests are popular tests of the bursting type. Plate 42, A, illustrates one of the several machines used for making the bursting-strength test.

The bursting-strength tests indicate certain qualities of the board from which fiber boxes are made, but such tests do not give an accurate measure of the relative serviceability of different fiber boxes since they reflect the strength of the board in the machine direction only and do not test the scores, which are the weakest part of the box. The results from these tests are influenced by a number of conditions, such as the rate of applying pressure, the condition of the board, and the calibration of the testing machine (*19*).

FIBER-BOARD SCORE TEST

The paper-board score tester shown in Plate 42, B, was designed by the Forest Products Laboratory to test the scores of fiber boxes. A specimen containing the scored edge is cut from the box and tested in combined bending, tearing, and tension by means of this machine.

On the machine are two clamps, one mounted on a stationary inclined ledge at the top and the other on an oscillating arm. The oscillating arm is connected with a driving mechanism by means of which it can be made to swing through various angles and at different speeds. The movable clamp is connected through a calibrated compression spring to a screw and ratchet wheel which causes a downward movement of the movable clamp when the oscillating arm moves back and forth.

The test specimen, which is 1 inch wide and about 4½ inches long, has the score midway between its ends and at right angles to its length. It is first bent through an angle of 90° at the score, and is then clamped in the machine with the score resting at the sloping edge at the end of the extension of the lower jaw of the stationary clamp. Thus when the machine is in motion, the specimen is bent back and forth at the sloping edge, and the tension caused by the force applied to the movable clamp causes the specimen to tear along the sloping edge. This action simulates the conditions which are encountered by the edges or scores of a loaded fiber box when it is subjected to rough handling or to the skewing and racking caused by the swaying of a moving freight car. The test is continued until the specimen fails, and the maximum pull and the total number of bends which the specimen withstood are taken as measures of the ability of the box to withstand rough handling.

The degree or intensity of the tearing can be changed to simulate different conditions by modification of the sloping edge together with the possible variations in speed, angle of swing of the oscillating arm, and rate at which the tension is increased. A combined bending and tension action without tearing can be obtained by using an edge having a horizontal ledge over which the tension and bending is applied to the specimen instead of a ledge having a slope or inclination. Tests on the scored edges of the box are especially valuable for determining the efficiency of the method used in making the score.

APPENDIX E. FORMULAS AND RULES FOR THE DESIGN OF BOXES

As a result of years of active study of shipping containers under laboratory and service conditions, engineers at the Forest Products Laboratory have worked out formulas for determining the thicknesses of material required in sides, top, and bottom of boxes of certain types. Rules from which the dimensions of other features may be so determined as to produce well-balanced construction have also been devised.

The principal features of these formulas and rules have been in print in tentative form for a number of years. During this period they have been subjected to study and criticism by shippers and by box manufacturers and have been extensively used as a guide in the design of boxes and in the preparation of specifications, improvements and modifications have been made from time to time.

As previously emphasized, it is seldom possible to determine the best design of a container other than by making successive improvements to correct weaknesses developed in service. The presentation of rules and formulas in this appendix is not in contradiction of, or inconsistent with, this statement. One purpose of the rules and formulas is to afford designs that can be placed in service and subjected to the improvement process. Another and perhaps more important object in presenting formulas and rules is to afford a framework to which further experience with various commodities may be related and thus determine proper values for factors that appear in the formulas and whose values are now unknown except for a loosely defined class of "average commodities." Determination of the proper values of these factors for any commodity amounts to a classification of the commodity. Such classification places considerable limitation on the use of formulas for designing boxes, since little has yet been accomplished in the classification of commodities.

The following scheme of commodity classification has been tentatively set up for use with the formulas.

TENTATIVE COMMODITY CLASSES

1. Those commodities that offer support to containers, are little damaged by local punctures, and in which the contents are of a nature to absorb considerable shock. Example—lump sugar in cartons.

2. Same as class 1 except that the commodity either does not absorb so much shock or needs greater protection. Example—ordinary canned goods.

3 and 4. Intermediate between 2 and 5.

5. Those commodities that do not offer support to the containers, absorb little of the shock, and are badly damaged by punctures.

The formulas and rules herein presented have been incorporated in certain specifications as a means of defining minimum dimensions of box parts. (See specifications for wooden boxes, nailed and locked-corner construction, and for wire-bound boxes, Appendix G.)

NAILED AND LOCKED-CORNER BOXES

THICKNESS OF SIDES, TOPS, AND BOTTOMS OF NAILED BOXES

FORMULA 1

The first formula [12] for the thickness (t_1) of the side, top, or bottom of a nailed box is

$$t_1 = K\sqrt{\frac{W}{b}} \tag{1}$$

where b = width in inches of side, top, or bottom whose thickness is to be found
W = gross weight of box, that is, the weight of contents plus the estimated weight of box
K = a factor whose value depends on the style of box, species [13] of wood, class of commodity, nature of transportation and storage conditions, and number of straps with which the box is reinforced.

The value of K also depends upon the internal packing. Suitable values of K have been determined for only a few sets of conditions. For unstrapped boxes carrying average commodities in domestic shipment, values of one-eighth and one-tenth for Group [14] 1–2 and Group 3–4 woods, respectively, have been found to give very satisfactory results.

FORMULA 2

Formula 1 does not take into consideration the length of the box. The influence of length on the thicknesses required is most important in boxes with long sides of relatively thin material in which the bending of the boards works the nails loose, and in boxes with relatively thick short sides, in which failures occur from the direct pull of the contents on the nails. The need for thinner material in relatively short boxes and for thicker material in long boxes is taken into account in a second formula for the thickness (t_2) of side, top, or bottom. This second formula is

$$t_2^{7/6} = K\sqrt{\frac{W}{b}}\sqrt[6]{\frac{L}{60}} \tag{2}$$

where L = length of box in inches and K, W, and b have the same meaning as in formula 1.

Formula 2 may also be written as

$$t_2 = \left(t_1^6 \frac{L}{60}\right)^{1/7} \tag{3}$$

where t_1 = the thickness as determined by formula 1.

---

[12] Charts by means of which any of the formulas in this appendix can be easily solved are provided (pp. 90 and 91).

[13] For the purpose of determining the thicknesses of box parts the woods listed on pages 103 and 104 are divided as follows: Groups 1 and 2 are combined into a single group designated Group 1–2, and Groups 3 and 4 into a single group designated Group 3–4. The nailing requirements depend on which of the primary Groups 1, 2, 3, or 4 includes the species used for the box ends and cleats.

[14] Box parts made of Group 3–4 woods may be 20 per cent less in thickness than if made of woods of Group 1–2. Hence, for any one combination of commodity class and shipping conditions the value of K is 20 per cent less for Group 3–4 than for Group 1–2 woods.

If the ratio of length to thickness of side, top, or bottom as determined by formula 1 exceeds 60, formula 2 will indicate a slightly greater thickness. If this ratio is less than 60, formula 2 will indicate a slightly smaller thickness. The difference in thicknesses as determined by the two formulas will not exceed 5 per cent for ratios between the limits of 45 and 80.

These formulas give the minimum required thicknesses of lumber surfaced on one side. If any thickness as found by formula is not an available one, the next greater available thickness should be used.

CHARTS FOR THE SOLUTION OF FORMULAS

In Figure 26[15] and Figure 27 are provided charts for the solution of formulas 1 and 3, respectively. The thickness t_2 may be obtained by first finding from Figure 26 the value of t_1, the thickness required by formula 1, and then by using Figure 27.

TABLE 11.—*Values of K used in Figure 26*

Commodity	Species group	Un-strapped box	One-strap box	Two-strap box
Class 1	1–2	0.100	0.080	0.064
	3–4	.080	.064	.051
Class 2	1–2	.125	.100	.080
	3–4	.100	.080	.064
Class 3	1–2	.156	.125	.100
	3–4	.125	.100	.080
Class 4	1–2	.195	.156	.125
	3–4	.156	.125	.100
Class 5	1–2	.244	.195	.156
	3–4	.195	.156	.125

HOW TO USE THE CHARTS

FIGURE 26, FORMULA 1

If an unstrapped box has been selected, for Group 1 and 2 woods place 1.0, and for Group 3 and 4 woods place 0.8, on the thickness scale[16] opposite the commodity class on the scale representing the kind of box to be used.

If a strapped box has been selected, for Group 1 and 2 woods place 0.1, and for Group 3 and 4 woods place 0.08, on the thickness scale opposite the commodity class on the scale representing a box with one or two straps, as the case may be.

Place a line, rubber band, or straight edge between the weight on the left-hand scale and the width on the right-hand scale. Read the thickness at the intersection of this line with the center line of the thickness scale.

FIGURE 27, FORMULA 3

(1) Find t_1, the thickness required by formula 1 from Figure 26.

(2) Connect this value of t_1 on the left-hand scale of Figure 27 to the length of the box on the right-hand scale by a line and at the intersection of this line with the middle scale read t_2, the thickness required by formula 2 or 3.

DIMENSIONS OF OTHER BOX PARTS

The required thicknesses of sides, top, and bottom of nailed boxes having been determined, thicknesses (of ends, sides, tops, and bottoms) for locked-corner boxes, dimensions of other parts of nailed boxes, and modifications allowable where boxes are strapped may be determined by rules devised for the purpose. Experience has shown that the application of these rules produces a good balance of box construction. The rules, which are stated in the following paragraphs, give minimum dimensions. The required thicknesses of box parts are often stated as the ratios of their thickness to the thickness of sides. These ratios are

[15] Figure 26 is based on values of K as listed in Table 11.

[16] If the thickness scale (the strip marked "thickness of side, top, or bottom") is slit along its side and end borders it can be readily placed in the desired position. The entire chart may be removed from the bulletin and mounted for convenience in use.

to be applied to the required thickness of side as found by formula and not to the available thickness adopted for use.

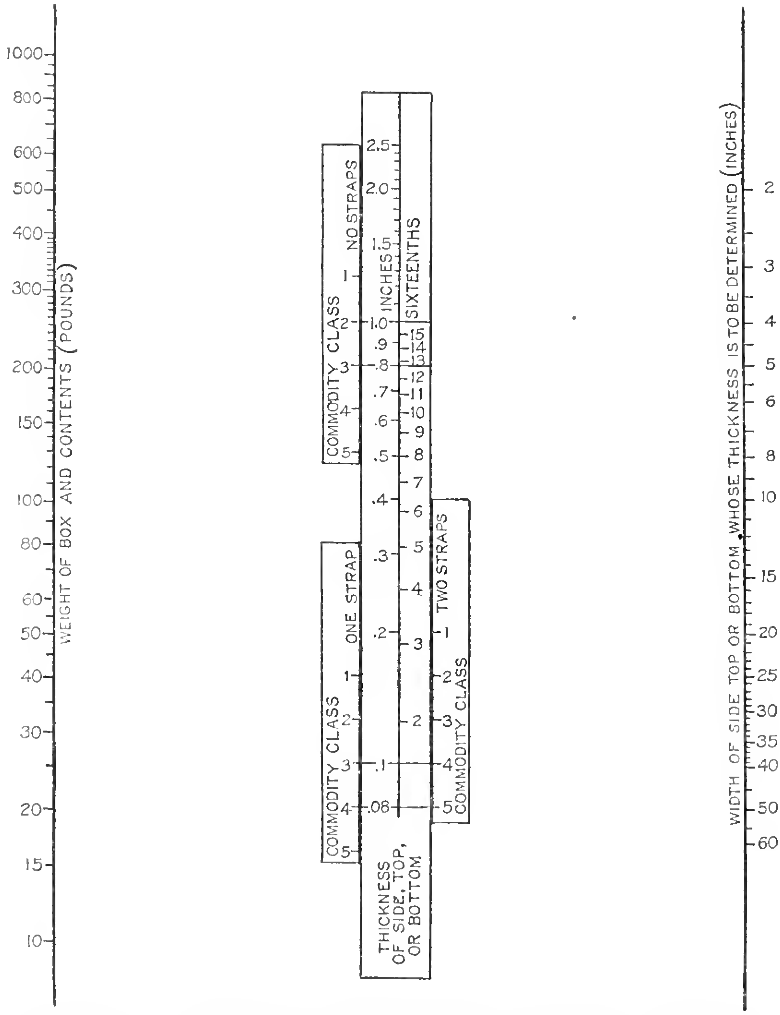


FIGURE 26.—Chart for determining thickness of sides, tops, and bottoms of nailed boxes by formula 1—length of box not taken into account: Commodity class 1, those commodities which offer support to containers, are little damaged by local punctures, and in which the contents are of a nature to absorb considerable shock. Example—lump sugar in cartons. Commodity class 2, same as class 1 except that the commodity either does not absorb so much shock or needs greater protection. Example—ordinary canned goods. Commodity class 5, those commodities which do not offer support to the container, absorb little of the shock, and are badly damaged by punctures. Commodity classes 3 and 4, intermediate between 2 and 5

THICKNESSES FOR LOCKED-CORNER BOXES

1. Tops and bottoms of locked-corner boxes: (*a*) Same thicknesses as required for nailed boxes.

2. Ends and sides of locked-corner boxes: (*a*) Ends and sides should contain not less than the total amount of lumber required for the ends and sides of uncleated-end nailed boxes, and in no case should the thickness of the ends be less than one and one-half times the thickness required for the sides of unstrapped nailed boxes. Sides whose ratio of length to thickness is less than 40 should be not less than the

thickness required for nailed boxes; sides whose ratio of length to thickness is greater than 40 should be not less than one and one-fourth times the thickness required for nailed boxes.

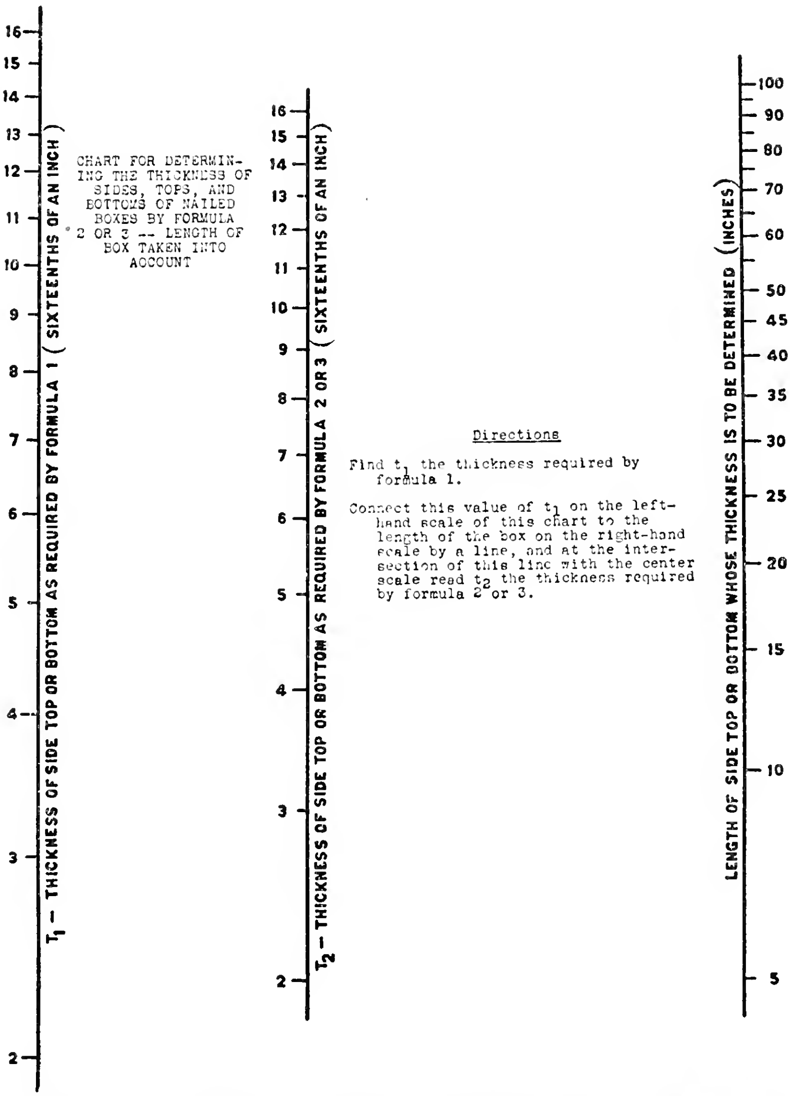


FIGURE 27.—Chart for determining the thickness of sides, tops, and bottoms of nailed boxes by formulas 2 or 3—length of box taken into account

THICKNESS OF ENDS AND CLEATS—NAILED BOXES

1. Style 1 (uncleated) boxes: (*a*) Ends two times the thickness required for sides.

2. Styles 4 and 5 (single cleated) boxes: (*a*) Ends and cleats each one and one-half times the thickness required for sides—sides nailed to both ends and cleats. (*b*) Ends one and three-fourths times the thickness required for sides—cleats not thinner than sides—sides nailed to ends only.

3. Styles 2 and 2½ (double cleated) boxes: (*a*) Ends and cleats each one and one-fourth times the thickness required for sides—sides, top, and bottom nailed to both ends and cleats. Applies also to style 3. (*b*) Cleats one and one-half times the thickness and cleats not less in thickness than required for sides—sides, top, and bottom nailed only to the cleats. Does not apply to style 3.

4. Ends and cleats of Group 3–4 woods may be 20 per cent less in thickness than if Group 1–2 woods are used.

Width of Cleats

The cleats for ordinary boxes should be not less in width than three times their thickness. Very long cleats, however, should exceed this width in order to prevent breaking across the grain. Triangular or square cleats used for style 5 boxes may be not less in cross sectional area than the requirements for ordinary rectangular cleats.

Nailing of Sides, Tops, and Bottoms to Ends and Cleats

If the nails are driven in a single row as in the top and bottom of a style 4 box and the piece holding the points of the nails is of the Groups 2 or 3 woods of thickness one and one-half times the thickness required for the sides, top, and bottom, the size of the nail in pennies should not be greater than the thickness of the piece holding the points, expressed in eighths of an inch. For Group 1 woods, the nails may be one size larger and sometimes even two sizes for the very soft coniferous woods, but for Group 4 woods the nails should be one size smaller. If 6d nails are required, they should not be spaced over 2 inches when held in the side grain and not over 1¾ inches when held in the end grain. The spacing should be correspondingly decreased one-fourth inch for each size below 6d and increased one-fourth inch for each size above 6d. Where the two pieces fastened together are of equal thickness, the nails may be one size larger than required by the foregoing rule with no increase in spacing. Where the thickness of the piece under the nail head is less than two-thirds the thickness of the piece holding the nail point, nails one or two sizes smaller should be used than is required where the piece under the nail head has a greater thickness, and the spacing should be correspondingly reduced one-half inch for each reduction in size of nail.

Where the nails are driven in two rows as in the style 2 box and the thickness of the ends and cleats are each one and one-fourth times the thickness of the sides, the nails should be spaced about one-fourth inch closer than required for a style 4 box having the same thickness of ends and cleats.

Fastening Cleats to Ends

In fastening cleats to the ends of boxes, the nails should not only be clinched but should also be driven in two rows near the edges of the cleats and spaced approximately the same as in the ends of the adjacent side, top, or bottom. See Figure 28 for details of nailing cleats to the box ends. If the box ends are thinner than the cleats, the nail heads should bear against the end pieces to resist more effectively pulling away of the ends from the cleats.

Corrugated Fasteners

Two pieces one-half inch or more in thickness joined with corrugated fasteners approximate the strength of a single piece where the corrugated fasteners are spaced approximately 8 inches along the joint and are driven alternately from both sides to a depth slightly less than the thickness of the pieces into which they are driven. Fasteners 1⅛ inches in length across the joint usually do not pull out of the material. Corrugated fasteners are much less effective when driven from one side than when driven alternately from both sides. Corrugated fasteners placed in a glued joint hold the joint while the glue is setting and produce a more rigid joint than corrugated fasteners alone.

Thicknesses of Sides, Top, and Bottom of Strapped Boxes

If nailed or locked-corner boxes of any style are strapped as defined under metal straps in the following paragraph, the thicknesses of the sides, top, and bottom may be reduced 20 per cent where one strap is used or 36 per cent where two straps are used. The use of straps does not justify any reduction in thickness of the box ends or cleats. Consequently, in applying the rules for thickness of ends and cleats the thickness of the sides that would be required for a box

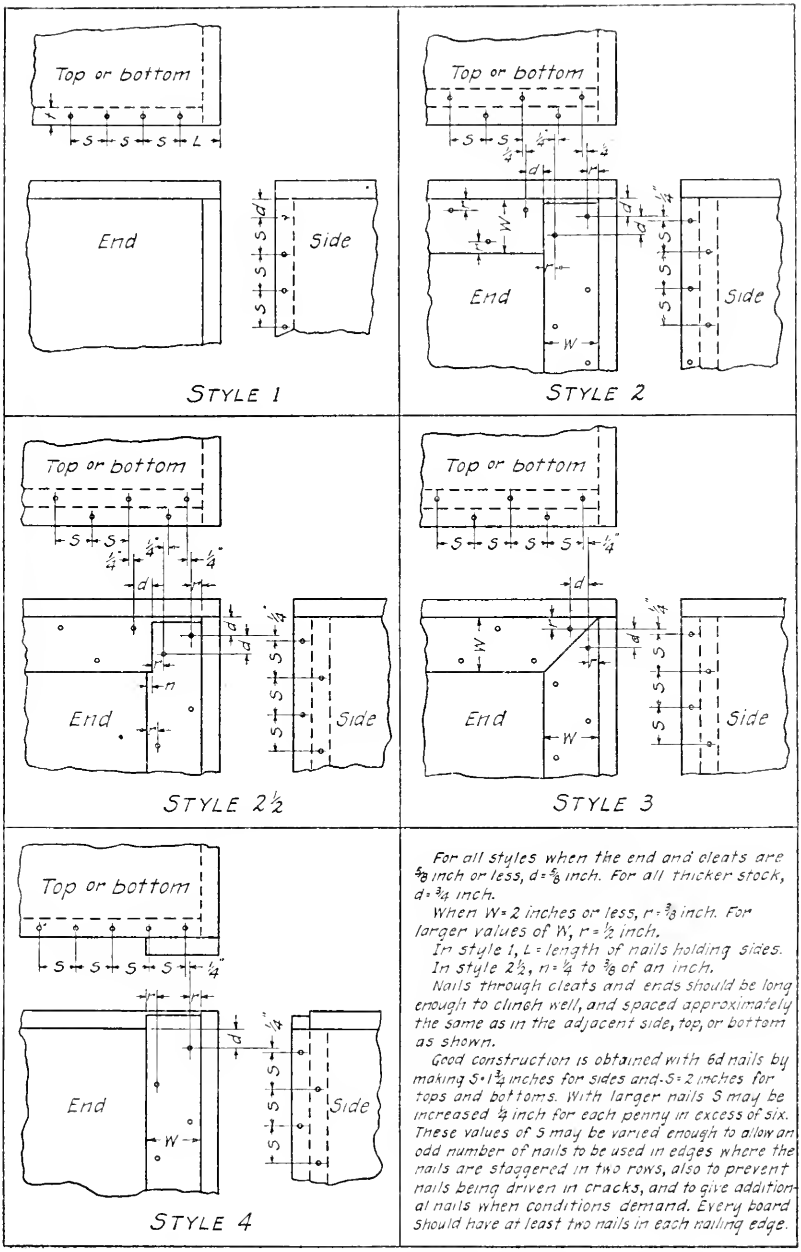


FIGURE 28.—Details for nailing standard styles of boxes for domestic shipment

without straps should be used as the basis for the ratio of end to side thickness. The reduction in the thicknesses of sides, top, and bottom by the addition of straps makes advisable some changes in the nailing of the sides, top, and bottom to ends and cleats. (See nailing of strapped boxes, p. 108.)

Metal Straps

When two or more nailless straps (flat steel straps or steel wires) are used, the two outer straps should be applied approximately one-sixth the length of the box from the ends, and the other straps spaced evenly between them. Nailed steel straps should be applied around the ends of the box or may be spaced the same as nailless straps if they are fastened to battens.

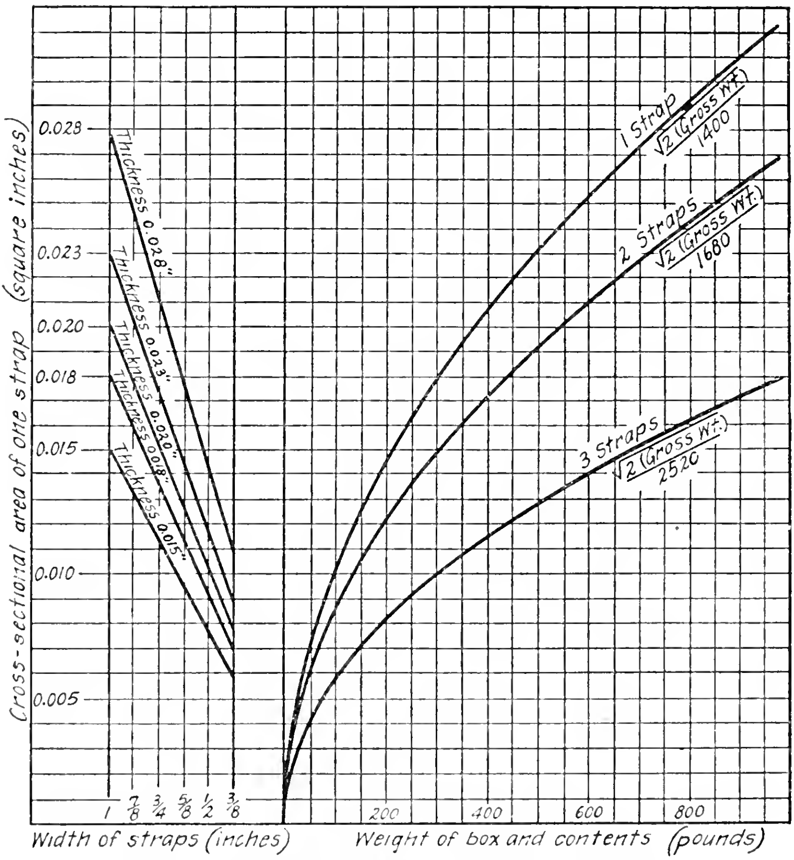


Figure 29.—Recommended sizes of flat metal straps for nailed boxes

The total cross-sectional area of the strapping, in square inches, should equal approximately one one-thousand-four-hundredths of the square root of twice the gross weight of the box and contents in pounds for one strap, and one eight-hundred-and-fortieths of the same quantity for two or more straps; thus, for two straps each one will be one one-thousand-six-hundred-and-eightieths of the quantity, and for three straps each one will be one two-thousand-five-hundred-and-twentieths of the quantity. Larger straps apparently do not add a proportional increase to the strength of the box, while smaller straps reduce the serviceability of the box more than in proportion to the reduction in size of the strap. This relation of strap sizes applies to wires as well as to both nailed and nailless flat metal straps. The seals fastening the ends of nailless strapping should develop at least 60 per cent of the tensile strength of the strapping. The size of strapping required for boxes carrying different loads is shown in Figure 29.

To find the required size for one, two, or three straps, use the chart as follows: Starting with the weight of the box and contents, move directly upward to the curve for the number of straps decided upon, then move horizontally to the left to the line representing the thickness of the strap to be used. The first vertical line at or beyond this point represents the width of strap required. Or, move from the curve to the left, to the vertical line representing the width of the strap decided upon, and the first diagonal line at or above this point represents the thickness of strap required.

Thickness of Single-Piece Sides

When the sides of nailed and locked-corner boxes are made of single-piece stock they may be $12\frac{1}{2}$ per cent less in thickness than that required by the preceding formulas and rules.

Thickness of Parts Surfaced on Two Sides

When the material is surfaced on two sides, the parts may be one thirty-second inch less in thickness than that required by the preceding formulas and rules.

WIRE-BOUND BOXES

THICKNESS OF SHEET MATERIAL

Three formulas for the thickness of sheet material required [17] in a wire-bound box have been devised and charts for their easy solution are presented on pages 97 to 100. Which of these should be used depends on certain relations between the weight of the contents and the average of the width and depth of the box.

In the following formulas—

t = thickness of sheet material in inches.
W = weight of contents in pounds.
b = average of width and depth of box in inches.
K_1, K_2, and K_3 are factors in the formulas for thickness. Their values depend on the nature of the commodity, the species of wood used, and the transportation conditions. For the same class of commodity and for the same transportation conditions the values of K_1, K_2, and K_3 should be 20 per cent greater for Group 1 woods and 10 per cent greater for Group 2 woods than for Group 3 woods, but may be 10 per cent less for Group 4 woods.
C_1 and C_2 are experimental values in supplementary equations defining the limits within which the three formulas apply.

1. For boxes with heavy contents and with narrow faces, a minimum cross-sectional area (thickness multiplied by width) is required to prevent the breaking of the sheet material near the corners of the box and near the end wires. This cross-sectional area varies with the weight of contents according to the formula

$$tb = K_1 W^{3/5} \qquad (4)$$

from which is derived the formula

$$t = K_1 \frac{W^{3/5}}{b} \qquad (5)$$

Formula (5) applies where b does not exceed $C_1\sqrt[5]{W}$

2. For boxes where b is greater than $C_1\sqrt[5]{W}$ and does not exceed $C_2\sqrt[3]{W}$ the thickness required for a given value of b varies directly as the square root of the weight, and the thickness for a given weight varies inversely as the square root of b. This relation is expressed as

$$t = K_2\sqrt{\frac{W}{b}} \qquad (6)$$

---

[17] The thickness actually needed in the narrow faces is sometimes greater than that needed in the wide faces. However, since it is not practicable to use different thicknesses in the wide and narrow faces of the same box, the average of the width and depth of the boxes is used in the design formulas.

3. The thickness of material for boxes the average width of whose narrow faces (b) exceeds $C_2\sqrt[3]{W}$ is that required to prevent mashing at the box corners and is given by

$$t = K_3\sqrt[3]{W} \tag{7}$$

The following values of the factors used in defining the limits of formulas 5, 6, and 7 have been found to give satisfactory results in designing boxes of rotary-cut lumber of Group 3 woods that carry commodities requiring average protection:

$K_1 = 0.105.$
$K_2 = 0.057.$
$K_3 = 0.034.$
$C_1 = 3.33.$
$C_2 = 2.85.$

SIZE OF WIRE

The size of wire required depends upon the weight of the box contents and may be expressed by the formula

$$a = \frac{\sqrt{W}}{504} \tag{8}$$

where a equals the sum of the cross-sectional area of all the binding wires, and W equals weight of box contents. The cross-sectional area of each wire equals a divided by the number of wires used. This is the same general equation as that developed for determining the size of straps for nailed boxes, but requires slightly greater total cross-sectional area of wire for wire-bound boxes than for nailed boxes.

SPACING OF WIRES

Experience has shown that usually the end wires and adjacent intermediate wires (p. 25) need to be spaced closer than the other wires. The following is the maximum distance the wires not adjacent the end wires should be spaced to prevent excessive springing of the sheet material under the weight and wedging action of the contents and to produce a well-balanced box:

With 1/8-inch sides, top, and bottom, the maximum spacing of wires should not exceed 5 inches; with 1/6-inch or 3/16-inch material the maximum spacing should not exceed 6 inches; with 7/32-inch or 1/4-inch material the maximum spacing should not exceed 7 inches; with 5/16-inch material the maximum spacing should not exceed 8 inches; and with 3/8-inch material the maximum spacing should not exceed 9 inches.

BOX END REINFORCEMENT

With the standard cleat used in the ordinary wire-bound box construction the reinforcement required for the box ends depends upon the weight and nature of the contents and upon the size and shape of the box. The required thickness for the sides, top, and bottom is likewise dependent upon these same factors and in much the same way. The end reinforcements, therefore, can be approximately associated with the thickness required of the sides, tops, and bottoms.

With the standard cleat, the ends and cleats without reinforcements are stronger than necessary to balance the strength of 1/8-inch sides, top, and bottom, but produce a good balanced construction without additional reinforcements if used in combination with 3/16-inch sides, top, and bottom.

In boxes with 1/4-inch sides, top, and bottom the end cleats and stapling are weaker than the sides, top, and bottom. Reinforcing end battens (styles D, F, and X) nailed in place increase the strength of the box but do not add so much strength as a wire or strap placed lengthwise around the box and over the widest faces.

In boxes made of 5/16-inch sheet material the ends need to be reinforced with battens (styles M, N, O, or P) nailed in place or with two reinforcing wires or straps, one over the ends, top, and bottom, and one over the ends and sides.

The ends and cleats of boxes with 3/8-inch sides, top, and bottom should be reinforced with battens in addition to two wires or straps in order to balance the strength of the sides, top, and bottom.

While the laboratory has made no tests on wire-bound boxes with 9/16-inch and 1 1/8-inch cleats as against standard 13/16-inch cleats, general deductions would lead to the expectation that the 9/16-inch and the 1 1/8-inch cleats would be in approximate balance, respectively, with the 1/8-inch and with 5/16-inch sheet material.

The sum of the cross-sectional areas of the reinforcing wires or straps should be about one-fourth the total cross-sectional area of the binding wires as found from formula 8.

SPACING OF STAPLES IN WIRE-BOUND BOXES AND CRATES

It is common practice to space the staples in wire-bound boxes $1\frac{1}{2}$ to 2 inches. The strength of boxes for carrying very heavy loads may be increased by nailing the sheet material to the cleats and battens or by spacing the staples as close as 1 inch, in which event the box must be run through the fabricating machine a second time. In boxes with relatively wide faces and carrying light loads the staple spacing may often exceed 2 inches without detriment. In wire-bound crates at least two staples should be driven in each end of each slat and near the edges.

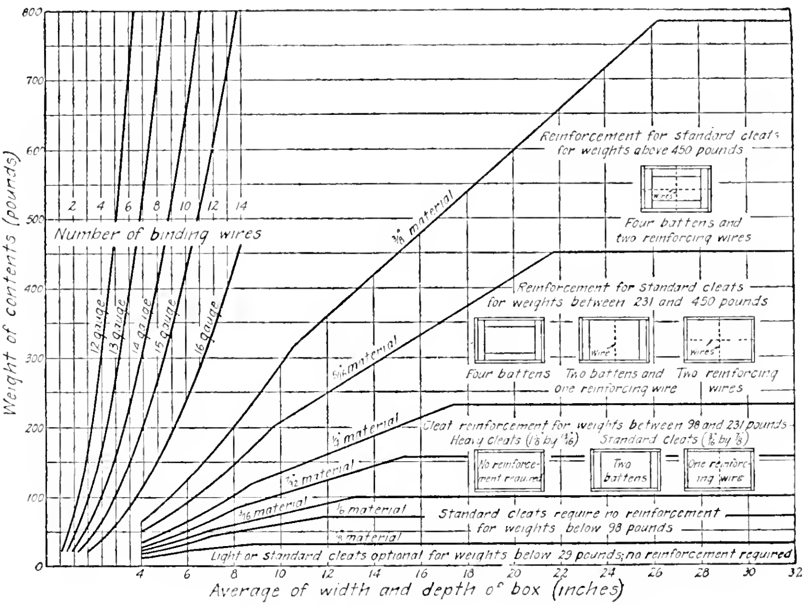


FIGURE 30.—Minimum thicknesses of sheet material and number and size of binding wires for wire-bound boxes made of Group 1 woods

CHARTS FOR DESIGNING WIRE-BOUND BOXES

Figures 30 to 33 are charts to facilitate solution of the formulas for determining sizes of parts and reinforcements for wire-bound boxes.

HOW TO USE THE CHARTS

THICKNESS OF MATERIAL

To determine the thickness of sheet material to be used, first select the chart pertaining to the species of wood under consideration. Starting with the weight of contents, follow the horizontal weight line from the scale at the left border of the chart to its intersection with the vertical line from the scale at the lower border representing the average of width and depth of box. At or above this intersection is the line representing the thickness of material.

NUMBER AND SIZE OF WIRES

To determine the number and size of wires to be used, start with the weight of the contents. Follow the horizontal weight line to its intersection with the curve representing the gauge of wire chosen. At or to the right of this intersection is the vertical line representing the number of wires.

For many weights there is a choice of gages and number of wires that may be used. The dimensions of the box and the fact that the wires should not be spaced closer than 4 inches to each other should be kept in mind, however, and the rules regarding maximum spacing of wires should be observed. These points may prove the determining factors in cases where a greater range of selection is otherwise indicated by the chart.

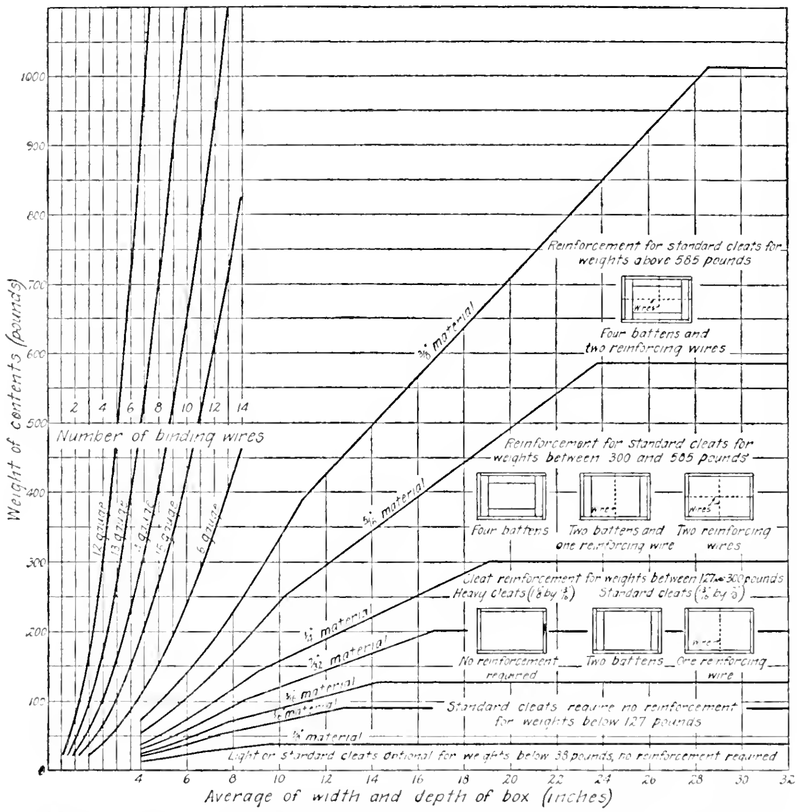


FIGURE 31.—Minimum thicknesses of sheet material and number and size of binding wires for wire-bound boxes made of Group 2 woods

APPENDIX F. DESCRIPTION OF TABLE 7

(See p. 56)

COLUMN 1, COMMON AND BOTANICAL NAMES OF SPECIES

Column 1 gives the common and botanical names of the various species of wood as adopted by the United States Forest Service (*18*).

COLUMN 2, NUMBER OF TREES TESTED

The number of trees tested shows the extent of work done on each species, and is an aid in estimating the reliability of the average figures. The greater the number of trees tested, the closer may the averages given be expected to approach the true average of the species.

COLUMN 3, SPECIFIC GRAVITY

Specific gravity is defined as the relation of the weight of a substance to that of an equal volume of water. The specific gravity values given in column 3 are based on the weight of wood when oven dry and its volume when green.

COLUMNS 4 AND 5, WEIGHT PER CUBIC FOOT

Ordinarily, wood is spoken of as "dry," or as "green" or "wet." In order to be correct, various stages of drying or dryness must be recognized in establishing the weight, not only because of the effect of the moisture content on weight, but because of change in volume with moisture changes.

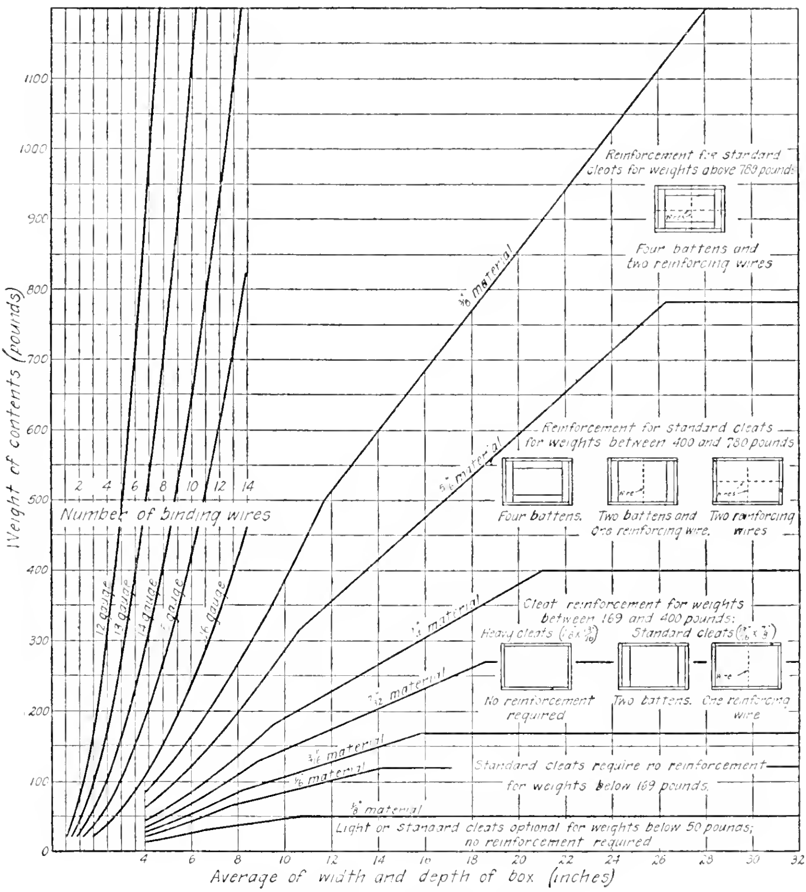


FIGURE 32.—Minimum thicknesses of sheet material and number and size of binding wires for wire-bound boxes made of Group 3 woods

When wood is green,[18] or freshly cut, it contains a considerable quantity of water. After wood has dried by exposure to the air until its weight is practically constant, it is said to be "air-dry." If dried in an oven at 212° F. until all moisture is driven off, wood is "oven-dry."

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[18] Green wood usually contains "absorbed" water within the cell walls and "free" water in the cell cavities. In drying, the free water from the cell cavities is the first to be evaporated. The fiber-saturation point is that point at which no water exists in the cell cavities of the timber but at which the cell walls are still saturated with moisture. The fiber-saturation point varies with the species. The ordinary proportion of moisture—based on the weight of the dry wood—at the fiber-saturation point is from 22 to 30 per cent. As a rule, the strength properties of wood begin to increase and shrinkage begins to occur when the fiber-saturation point is reached in seasoning. See p. 86 for method of determining moisture content of wood.

The weights of wood at two important stages are given in columns 4 and 5. The weight when green as given in column 4 includes the moisture present at the time the trees were cut. The moisture content of green timber varies greatly among different species. It also varies among different trees of the same species and different parts of the same tree. In most softwood species the sapwood has more moisture than the heartwood. For instance, the sapwood of southern yellow pine usually contains moisture in excess of 100 per cent, whereas the heartwood has only about 30 or 40 per cent moisture. Large variations in green weight, depending on the proportion of sapwood, may occur in species having a high moisture content in the sapwood. Softwood lumber in the green condition

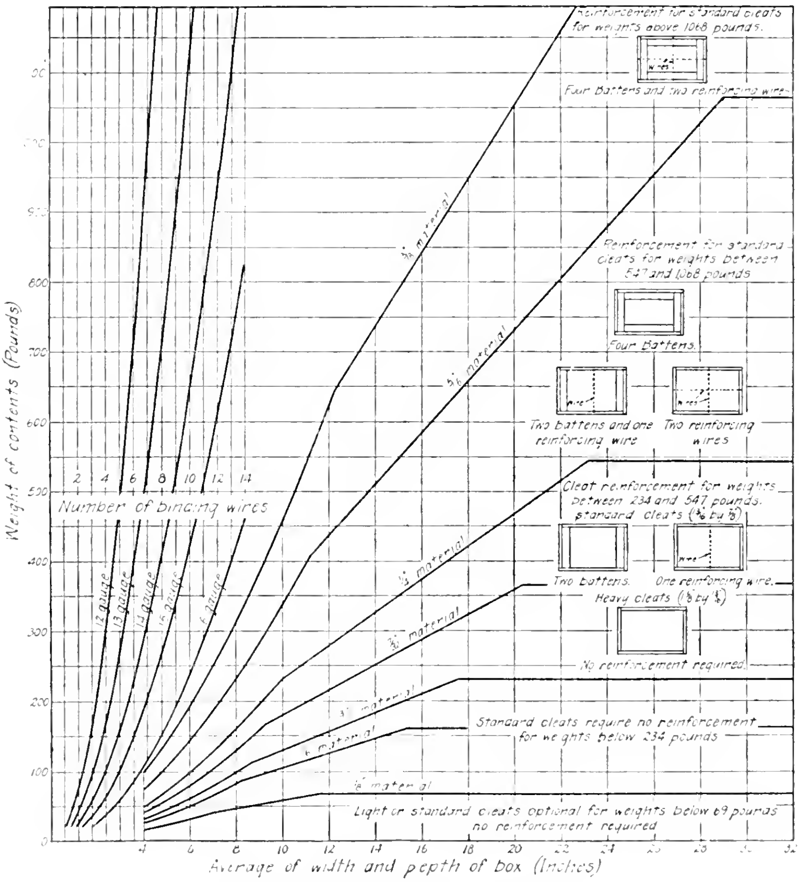

FIGURE 33. Minimum thicknesses of sheet material and number and size of binding wires for wire-bound boxes made of Group 4 woods

that is obtained from young trees averages heavier than that obtained from old trees because the young trees contain a larger proportion of sapwood.

The amount of moisture in air-dried wood depends on the size and form of the pieces, and the climate. The species vary widely in the rate at which they give off moisture in drying, and also in the rate at which they take up moisture during periods of wet or damp weather. The average air-dry condition reached in the North Central States by material 2 inches and less in thickness, when sheltered from rain and snow and without artificial heating, is a moisture content of about 12 per cent.[19] The figures given in column 5 are for this moisture content. The

[19] The moisture content of wood is commonly expressed as a percentage of the weight of the oven-dry or moisture-free wood. If a specimen from a board weighed 112 grams immediately after cut, and after oven drying was found to weigh 100 grams, it is said to have contained 12 per cent moisture.

moisture content of thoroughly air-dry material may be 3 to 5 per cent higher in humid regions, and in very dry climates, as much lower. Large timbers will have a higher average moisture content when thoroughly air-dry than boards or small dimension stock.

When the moisture content in comparatively dry wood changes, two actions which counteract one another take place and the weight per cubic foot changes but little. Thus, if the wood dries further, the weight per cubic foot becomes lower because of loss in moisture, while at the same time it increases because shrinkage causes the same wood substance to occupy less space. Conversely, if it absorbs moisture, both weight and volume are increased.

The weight of wood at any moisture content near 12 per cent may be estimated by assuming that a ½ per cent change in weight per cubic foot accompanies a 1 per cent change in moisture content. For example, wood at 8 per cent moisture content would weigh about 2 per cent less per cubic foot than at 12 per cent, whereas the weight at 14 per cent moisture would be about 1 per cent greater than at 12 per cent.

COLUMNS 6, 7, AND 8, SHRINKAGE

Shrinkage across the grain, that is, shrinkage in the width and thickness of boards, results when the wood loses some of the absorbed moisture. Likewise, swelling occurs when dry wood is soaked or when it takes up moisture from the air; much as a sponge gets larger when wet. Shrinkage of wood in the direction of the grain (length of boards or timbers) is usually too small to be of practical importance.

The figures in columns 6 and 7 are average values of the measured radial and tangential shrinkages which took place in drying small clear specimens from the green state to an oven-dry condition. Radial shrinkage is that across the annual growth rings in a cross section, such as in the width of a quarter-sawed board; tangential shrinkage that parallel to the curves of the annual growth rings in a cross section, such as in the width of a flat-sawed board.

Column 8 lists figures on the relative shrinkage in volume from the green to the oven-dry condition for the various species. These figures are computed from actual volume measurements of small clear specimens, combined with actual radial and tangential shrinkage measurements, the results of which are recorded in columns 6 and 7. Volumetric shrinkage values that are comparable with those of columns 6 and 7 may be obtained from column 8 by dividing the figures listed by 10.

The shrinkage which will take place in any piece of wood depends on a great many factors, some of which have not been thoroughly studied. In all species the tangential shrinkage is more than the radial, the average ratio being about 9 to 5. Hence, flat-sawed boards shrink less in width but more in the thickness than quarter-sawed or edge-grain boards. Ordinarily the less the difference between radial and tangential shrinkage, the less is the tendency to check in drying.

Air-drying wood is continually taking on or giving off moisture with changing weather or heating conditions. Time is required for these moisture changes, however, so there is always a lag between changes in air conditions and their full effect on the moisture condition of the wood. The lag is greater in some species than in others. As a result some species, whose shrinkage from the green to the oven-dry condition is large, do not cause as much inconvenience in use as woods with lower shrinkage, because the changes in dimensions do not follow atmospheric changes so closely. The shrinkage figures given do not take into account the readiness with which the species take on and give off moisture. Consequently they should be considered as the relative shrinkage between woods after long exposure to fairly uniform atmospheric conditions or to the same change in moisture content.

COLUMN 9, BENDING STRENGTH

Column 9 gives figures on bending strength. Bending strength is a measure of the load-carrying capacity of beams, which are usually horizontal members resting on two or more supports. Examples of beams are crate skids and box sides. The figures for bending strength afford a direct comparison of the breaking strength of clear beams of the various species.

If a species is low in bending strength, it does not necessarily follow that it is not suitable for use in boxes and crates. It does indicate, however, that larger sizes may be necessary than if species which rank higher in this property are used.

Box and crate parts are subjected to bending action and, while bending strength is of some importance, it is, particularly in sides, tops, and bottoms of boxes, of less importance than fastening resistance. As pointed out elsewhere, it is seldom possible to fasten box parts together securely enough to utilize the full bending strength of clear lumber.

COLUMN 10, COMPRESSIVE STRENGTH (ENDWISE)

The figures of column 10, compressive strength, apply to comparatively short compression members. Compression members in boxes and crates are usually rectangular in cross section, and support end loads which act in the direction of the length. Endwise compressive strength of short members is seldom a controlling factor in the selection of box and crate woods except where they are used for blocking the commodity in place.

When the length of a compression member becomes more than about 11 times its least dimension, it is classed as either an intermediate or a long column, and the values in column 10 do not apply.

When compression members are of a length more than about 11 times the least dimension, stiffness begins to be a factor in the strength, and at a length of 20 to 30 times the least dimension, as in diagonal braces and edge members of crates, it is the controlling property and the member is classed as a long column. The values in column 10 are not applicable to long columns.

If one species is lower in compressive strength than another, the difference may be compensated by using a member of correspondingly larger cross-sectional area.

COLUMN 11, STIFFNESS

When any weight or load is placed on a member, a deflection is produced. Stiffness is a measure of the resistance to deflection and relates particularly to beams. It is one of the properties required in diagonal braces for crates. The figures in column 11 give the average stiffness of the different species. Difference in stiffness between species may be compensated by changing the size of members.

COLUMN 12, HARDNESS

Hardness is the property which makes a surface difficult to dent or scratch. The harder the wood, other things being equal, the better it resists wear, the less it crushes or mashes under loads, and the better it can be polished; on the other hand, the more difficult it is to cut with tools, the harder it is to nail, and the more it splits in nailing. The greater the figure given in the table, the greater the hardness of the wood.

There is a pronounced difference in hardness between the spring wood and the summer wood of some species, such as southern yellow pine and Douglas fir. Where this is true, differences in surface hardness occur at close intervals, depending on whether spring wood or summer wood is encountered. In woods like maple, which do not have pronounced spring wood and summer wood, the hardness of the surface is more nearly uniform.

COLUMN 13, SHOCK RESISTANCE

Shock resistance is the capacity to withstand suddenly applied loads. Hence, woods high in shock resistance are resistant to repeated shock, jars, jolts, and blows. The greater the figure in the table, the greater is the shock resistance of the species.

PERCENTAGE ESTIMATED PROBABLE VARIATION

The percentage figures in the bottom two lines of Table 7 exclusive of footnotes offer a means of estimating the variability, a detailed discussion of which is given in the Comparative Strength Properties of Woods Grown in the United States (*12*).

The percentage figures in the last line of Table 7 indicate the variation, above and below the average, which may be expected to include half of all the material of a species. For example, consider the hardness of red alder in Table 7. The hardness (column 12) is 48, and the variation of an individual piece is 16 per cent. From these figures, it may be estimated that the hardness of one-half of the red alder would fall within the limits 40 and 56. The approximate proportion of material of a species falling within certain other percentages of the Table 7 values may be estimated on the basis of the following relations:

75 per cent is within 1.71 times the percentage probable variation.
82 per cent is within 2.00 times the percentage probable variation.
90 per cent is within 2.41 times the percentage probable variation.
96 per cent is within 3.00 times the percentage probable variation.

The percentage figures in the next to last line indicate that there is an even chance that the true average is within these percentages of the figures in Table 7. The percentages given applying to species represented by various numbers of trees from 1 to 50 are presented in Comparative Strength Properties of Woods Grown in United States (*12*).

Mortality statistics upon which insurance rates are based tell very closely how many men of any large group will live to be a certain age, but they do not enable one to say whether John Doe at that age will be included among the living. In a similar manner, the variability figures given in the next to the last line of Table 7 permit one to estimate how many of the species of wood will have their averages raised or lowered by a specified amount by additional tests, but one can not say that red alder or any other designated species will be raised by this amount. Such calculations are of most value when applied to groups, but are less definite when applied to individual species.

APPENDIX G. SPECIFICATIONS

The following specifications are given as examples of the application of the principles, formulas, and rules presented in this bulletin and as a guide for obtaining containers of balanced construction. These specifications have been prepared by the container committee of the Federal Specifications Board.[20] This specification for nailed and locked-corner boxes is a revision of the specification which was adopted by the American Society for Testing Materials as tentative standard in 1920. It retains the salient features of the older specification but new information which has been approved by leading manufacturers, shippers, and carriers has been added.

PROPOSED UNITED STATES GOVERNMENT MASTER SPECIFICATION FOR BOXES, WOODEN, NAILED AND LOCKED-CORNER CONSTRUCTION

I. GENERAL SPECIFICATIONS

There are no general specifications applicable to this specification.

II. STYLES

This specification covers two forms of construction, nailed, styles 1, 2, 2½, 3, 4, and 5, and locked-corner, style 6. (Pl. 1.)

III. MATERIALS AND WORKMANSHIP

1. Material:
   (*a*) Lumber—
      (1) Seasoning.—All pieces shall be made of well-seasoned lumber.
      (2) Defects.—The pieces shall show no defects that materially weaken them, expose the contents of the box to damage, or interfere with the prescribed nailing.
      No knot or knot hole shall have a diameter exceeding one-third of the width of the piece.
      (3) Species of wood.—The principal woods used for boxes are classified as follows:

GROUP 1

COMMON NAME

Aspen.
Aspen, largetooth.
Basswood.
Butternut.
Buckeye, yellow.
Cedar, northern white.
Cedar, Port Orford.
Cedar, western red.
Chestnut.
Cottonwood, black.
Cottonwood, eastern.
Cypress, southern.
Fir, alpine.
Fir, balsam.
Fir, California red.
Fir, lowland white.
Fir, noble.
Fir, silver.
Fir, white.
Magnolia, cucumber.
Magnolia, evergreen.
Pine, jack.
Pine, lodgepole.
Pine, northern white.
Pine, Norway.
Pine, sugar.
Pine, western white.
Pine, western yellow.
Poplar, yellow.
Redwood.
Spruce, Engelmann.
Spruce, red.
Spruce, Sitka.
Spruce, white.
Willow, black.
Willow, western black

[20] The Federal Specifications Board was organized under the Bureau of the Budget in 1921. It is composed of representatives of each of the purchasing units of the United States Government, the director of the Bureau of Standards being chairman of the board ex-officio. Its purpose is to unify Government specifications and to bring them into harmony with the best commercial practice wherever the conditions permit. The Government specifications are submitted before adoption for criticism by industry.

Group 2

COMMON NAME

Fir, Douglas.
Hemlock, eastern.
Hemlock, western.
Larch, western.
Pine, loblolly.
Pine, longleaf.
Pine, mountain.
Pine, pitch.
Pine, pond.
Pine, shortleaf.
Pine, slash.
Tamarack.

Group 3

COMMON NAME

Ash, black.
Ash, pumpkin.
Elm, American.
Gum, black.
Gum, red.
Gum, tupelo.
Maple, silver.
Sycamore.

Group 4

COMMON NAME

Ash, green.
Ash, white.
Beech.
Birch, sweet.
Birch, yellow.
Elm, rock.
Elm, slippery.
Hackberry.
Hickory.
Maple, black.
Maple, sugar.
Oaks, red.
Oaks, white.

(*b*) Nails—Cement-coated nails of the dimensions given in Table 12 shall be used. Uncoated nails may be used in accordance with Section IV. 6 (*a*) and IV. 7 (*b*) (2).

TABLE 12.—*Dimensions of cement-coated steel wire nails*

Size of nails	Length	Cooler and sinker nails [1] (Washburn & Moen)	Standard box nails (Washburn & Moen)
	Inches	*Gage No.*	*Gage No.*
Twopenny	1	16	16½
Threepenny	1⅛	15½	16
Fourpenny	1⅜	14	15½
Fivepenny	1⅝	13½	15
Sixpenny	1⅞	13	13½
Sevenpenny	2⅛	12½	13½
Eightpenny	2⅜	11½	12½
Ninepenny	2⅝	11½	12½
Tenpenny	2⅞	11	11½

[1] Cooler nails and sinker nails are identical except for their heads. The head of the cooler nail is flat on the underside, while the head of the sinker nail is cone shaped on the underside and slightly smaller. Either can be used in a nailing machine. Standard box nails are the same length as cooler nails and sinker nails, but are smaller in diameter.

(*c*) Strapping—

(1) Either round or flat metal straps may be used. When used without nails, flat strapping shall have a tensile strength of approximately 84,000 pounds per square inch, and round strapping shall have a tensile strength of not less than 60,000 pounds per square inch. When used with nails, round or flat strapping shall have a tensile strength of not less than 60,000 nor more than 84,000 pounds per square inch.

(2) Seals used to hold together the ends of nailless straps shall have not less than 60 per cent of the tensile strength of the strap.

2. Workmanship:

(*a*) Fabrication—All parts of the box shall be cut to size and the box shall be fabricated in accordance with good commercial practice.

(*b*) Variation in thickness—The wooden parts shall average not less than the required thickness. Occasional variations in thickness due to mismanufacture will be permitted in not over 10 per cent of the pieces but no part of any piece shall be less than seven-eighths the required thickness.

(*c*) Driving of nails: Nails shall be driven so as not to project above the surface of the wood. Occasional overdriving of nails will be permitted but no nail shall be overdriven more than one-eighth the thickness of the piece.

IV. GENERAL REQUIREMENTS

1. Thickness of parts of unstrapped boxes:
   (*a*) Thickness by formula—The thickness of the sides and of the top and bottom shall not be less than the thickness computed by the following formula:

$$t=\frac{1}{8}\sqrt{\frac{w}{b}}$$

in which t=thickness of sides, or of top or bottom—inches
w=gross weight of the box and its contents—pounds
b=width of a side or width of top or bottom—inches

Example.—What is the thickness of ends, cleats, sides, top, and bottom of a style 2 box, 36 inches long, 22¼ inches wide, and 12½

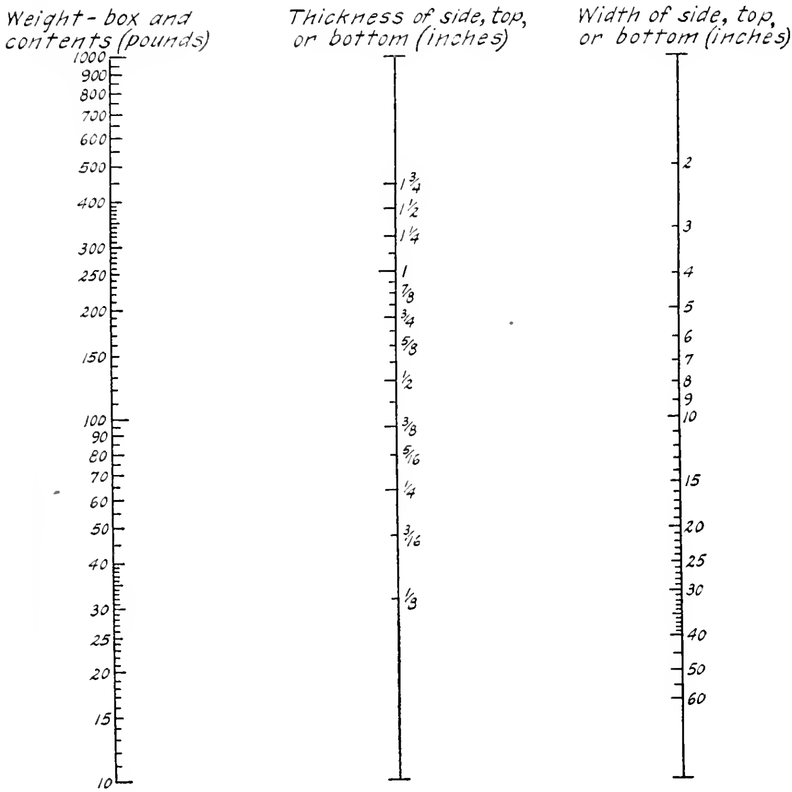

FIGURE 34.—Chart for determining the thickness of side, top, or bottom of unstrapped boxes

inches deep, for carrying a net load of 190 pounds? Estimated gross weight of box and contents, 200 pounds.

$$t \text{ (of side)}=\frac{1}{8}\sqrt{\frac{200}{12.5}}=\frac{1}{2}\text{ inch}$$

$$t \text{ (of top or bottom)}=\frac{1}{8}\sqrt{\frac{200}{22.25}}=\frac{3}{8}\text{ inch}$$

From Section V. 2 (*b*), the ends and cleats may each be one and one-fourth times the thickness of the sides, which could be five-eighth inch; or from Section V. 2 (*c*), the ends may be equal to the sides in thickness if the thickness of the cleats is one and one-half times the thickness of the sides, which would be three-quarters inch.

   (*b*) Thickness by chart—The thickness of the sides, top, and bottom may also be determined from the chart designated as Figure 34. This is done as follows: Place a straight edge on the chart so that it crosses the vertical left-hand scale at the point corresponding to the gross weight; pivot the straight edge on this point so that it crosses the vertical right-hand scale at the point corresponding to the width of the side, top, or bottom; the straight edge will then cross the middle scale at a point which will be the proper thickness for the part in question.

(*c*) Thickness of parts of various species of wood—The thickness of parts determined as indicated in Section IV. 1 (*a*) and (*b*) applies to parts made of the woods in Groups 1 and 2, Section III. 1 (*a*) (3). If the parts are made from woods in Groups 3 and 4, the thickness may be less than the specified value by the amount given in Table 13.

TABLE 13.—*Reduction in thickness of part if made of woods in Groups 3 and 4*

Specified thickness (woods in Groups 1 and 2)	Allowable reduction for woods in Groups 3 and 4
	Inch
¼ to ½ inch, inclusive	1/16
Over ½ to 1 inch, inclusive	⅛
Over 1 to 2 inches, inclusive	¼

(*d*) One-piece sides—

(1) Sides made from one piece of wood may be not less than seven-eighths of the thickness determined as indicated in Section IV.1 (*a*) and (*b*).

(2) Two or more pieces, which are Linderman jointed and glued, shall be considered one piece.

(3) Two or more pieces one-half inch or more in thickness and not less than 1½ inch in width at either end which are either butt-jointed or matched and which are fastened with corrugated fasteners shall be considered one piece. The corrugated fasteners shall be 1⅛ inches in length and shall penetrate about three-quarters the thickness of the material. They shall be spaced not more than 4 inches from the ends of the boards and not more than 8 inches apart. If three or more corrugated fasteners are used in a joint, they shall be driven alternately from opposite sides of the part.

2. Number of pieces in any part: The number of pieces in any part (namely, side, top, bottom, or end) shall not exceed the number given in Table 14.

TABLE 14.—*Number of pieces in any part*

Width of part	Maximum number of pieces
Under 4 inches	1.
4 to 7 inches	2.
7 to 10 inches	3.
10 inches and over	1 piece for each 3 inches of width. No piece shall be less than 2½ inches in width.

3. Thickness of parts of strapped boxes: The thicknesses of the sides, tops, and bottoms of strapped boxes may be less than those given for unstrapped boxes by the amounts given in Table 15.

TABLE 15.—*Thickness of sides, tops, and bottoms*

Unstrapped boxes	Strapped boxes with—		Unstrapped boxes	Strapped boxes with—	
	One strap	Two or more straps		One strap	Two or more straps
	Inch	*Inch*		*Inch*	*Inch*
⅞	⅝	½	½	⅜	5/16
13/16	⅝	½	7/16	5/16	¼
⅝	½	⅜	⅜	5/16	¼
9/16	7/16	5/16			

4. Uncleated ends:
   (*a*) Thickness—The ends shall not be less than twice the thickness required for sides, but no end shall be less than three-eighth inch thick.
   (*b*) Joining—
      (1) Ends made of two or more pieces seven-eighth inch or less in thickness shall be either, first, cleated; or second, butt jointed, or matched and fastened with corrugated fasteners, in accordance with Tables 16 and 17.

TABLE 16.—*Size of corrugated fasteners*

Thickness of box end	Size of fasteners
	Inches
⅜ inch	¼ by 1⅛
7/16, ½, and 9/16 inch	⅜ by 1⅛
⅝, 11/16, and ¾ inch	½ by 1⅛
13/16 and ⅞ inch	⅝ by 1⅛

TABLE 17.—*Number of fasteners*

Length of box end	Fasteners
	Number
16 inches and under	2
16 to 24 inches	3
24 to 36 inches	4

      (2) Two or more pieces Linderman jointed shall be considered one piece.

5. Surfacing:
   (*a*) Smoothness—The outside surface of the box shall be sufficiently smooth to permit legible marking.
   (*b*) Allowance for surfacing—If the boards are surfaced on both sides (to protect the contents), the thickness may be one-thirty-second inch less than the thickness required for boards surfaced on one side.
6. Nailing:
   (*a*) Uncoated nails—If nails which are not cement coated are used (except for cleats), the number of nails required shall be increased by 25 per cent.
   (*b*) Size of nails for unstrapped boxes—Cement-coated nails shall be of the size given in Table 18, depending upon the species of the wood and the thickness of the piece holding the points of the nails.

TABLE 18.—*Sizes of cement-coated cooler, sinker, and box nails for unstrapped boxes*

Species of wood	Size of nail used for nailing—										
	Sides, tops, and bottoms to ends or cleats of the thickness stated in parts of an inch								Top and bottom to side of the thickness stated in parts of an inch		
	⅜ or less	7/16	½	9/16	⅝	11/16 or ¾	13/16	⅞	Less than ½	½ to 9/16	⅝ to ⅞
	Penny	*Penny*	*Penny*	*Penny*	*Penny*	*Penny*	*Penny*	*Penny*	*Penny*	*Penny*	*Penny*
Group 1	4	5	5	6	7	8	8	9	4	6	7
Group 2	4	4	5	5	6	7	7	8	4	5	6
Group 3	3	4	4	5	5	6	7	7	3	4	5
Group 4	3	3	4	4	4	5	6	7	3	4	5

   (*c*) Spacing of nails—
      (1) Nails holding the side, top, or bottom to the ends shall be spaced about as given in Table 19.

TABLE 19.—*Spacing of cement-coated nails for unstrapped boxes*

Size of nail	Spacing when driven into—	
	Side grain of end	End grain of end
	Inches	*Inches*
Sixpenny or smaller	2	1¾
Sevenpenny	2¼	2
Eightpenny	2½	2¼
Ninepenny	2¾	2½
Tenpenny	3	2¾

(2) The next smaller nails than the size required by Table 18 may be used for unstrapped boxes, but they shall be spaced one-fourth inch closer than required by Table 19 for the size of nail used.

(3) Each board in the side, top, or bottom shall have at least two nails at each nailing end, except that boards less than 2½ inches in width which are, (1), Linderman jointed, or (2), either butt jointed or matched and are fastened with corrugated fasteners as required by Section IV. 1 (*d*) (3) may have only on nail.

(4) If the sides are less than one-half inch in thickness, neither the top nor the bottom shall be nailed to the sides unless the order requires side nailing.

(5) When ends and cleats are the same thickness, approximately half of the nails in the ends of the sides, top, and bottom shall be driven into the ends and the remainder into the cleats.

(6) If the top or bottom is nailed to the side, the nails shall be spaced between 6 and 8 inches.

(7) When the sides, top, and bottom of strapped boxes are reduced in accordance with the thicknesses given in Table 15 the boxes shall be fastened with the next smaller nail than the size required by Table 18 and they shall be spaced one-fourth inch closer than required by Table 19 for the size of nails used.

7. Cleats:

(*a*) Widths—The width of cleats shall not be less than three times the required thickness.

(*b*) Nailing—

(1) Each piece of the end shall be nailed to each cleat with not less than two nails, except that boards less than 2½ inches in width which are joined in accordance with either Section IV. 1 (*d*) (2) or (3) may have only one nail.

(2) The nails shall pass through both the cleat and the end and be clinched. Either cement-coated or uncoated nails may be used. If the cleats are thicker than the ends, the nails shall be driven through the ends into the cleats and clinched.

(3) The nails in each cleat shall be driven in two rows spaced as given in Table 19.

8. Strapping:

(*a*) Size—Straps shall be of the size required by Figure 29, depending on the gross weight (box and contents).

(1) To find the size of flat straps from this diagram, start with the gross weight and move upward to the curve for the number of straps, then move horizontally toward the left to the line for the thickness of the strap. The width of the strap is given directly below this point. For example, weight 260 pounds, 2 straps, thickness 0.020 inch; the required width of strap is eleven-sixteenths inch and the next wider strap is three-fourths inch.

(2) To find the size of wire straps start with the gross weight and move upward to the curve for the number of straps, then move horizontally to the left to scale showing cross-sectional area of one strap. Determine from Table 20 the gage of wire having the required cross-sectional area. For example, weight 260 pounds, two wire straps. Required cross-sectional area is 0.014 square inch. From Table 20 it is found that 0.0143 square inch is the cross-sectional area of a 10-gage wire.

TABLE 20.—*Conversion of cross-sectional area of one strap to gage of wire*

Cross-sectional area of one wire	Washburn & Moen	Cross-sectional area of one wire	Washburn & Moen
Square inch	*Gage number*	*Square inch*	*Gage number*
0.0041	15	0.0127	10½
.0050	14	.0143	10
.0066	13	.0156	9½
.0075	12½	.0172	9
.0087	12	.0206	8
.0098	11½	.0246	7
.0114	11	.0290	6

(*b*) Tightness—All straps shall be drawn tight so as to sink into the edges of the box.

(*c*) Distance between straps—If two or more nailless straps are used, the distance between any strap and either end of the box shall not be less than one-sixth the length of the box.

(*d*) Nailing straps—If the straps are nailed, one shall be placed around each end of the box and secured by nails of the size required by Table 18 spaced twice the distance required by Table 19.

V. DETAIL REQUIREMENTS

1. Style 1. Nailed construction, no cleats:
   - (*a*) Construction—The box shall be made substantially as shown for style 1, Plate 1.
   - (*b*) Grain in ends—In the ends the grain of the wood shall run the long way.
   - (*c*) Allowable weight of box and contents—Several pieces in sides, style 1 boxes, having sides made from two or more pieces, may be used if the weight of the contents does not exceed 60 pounds.
   - (*d*) Allowable weight of box and contents—One-piece sides style 1 boxes, having single-piece sides of sawed lumber or veneer, may be used if the gross weight (box and contents) does not exceed 100 pounds.
2. Style 2. Nailed construction, having four cleats (plain) at each end:
   - (*a*) Construction—The box shall be made substantially as shown for style 2, Plate 1.
   - (*b*) Thickness of ends and cleats—Either the ends or the cleats shall be three-eighths or more in thickness. The thickness of the ends and cleats may be the same provided this thickness is not less than one and one-quarter times the required thickness of the sides.
   - (*c*) Thickness of ends and sides—The thickness of the ends and sides may be the same provided the thickness of the cleats is not less than one and one-half times the required thickness of the sides.
   - (*d*) Length of cleats—The ends of the cleats which run across the grain of the end boards shall be one-eighth inch from the inside surface of the top and bottom.
   - (*e*) Cleats overlapped—The sides, top, and bottom shall extend over the cleats.
   - (*f*) Allowable weight of box and contents—Boxes of style 2 may be used for any gross weight.

3. Style 2½. Nailed construction having four cleats (two notched) at each end:
   - (*a*) Construction—The box shall be made substantially as shown for style 2½, Plate 1.
   - (*b*) Thickness of ends and cleats—Either the ends or the cleats shall be three-eighths inch or more in thickness. The thickness of the ends and cleats may be the same provided this thickness is not less tahn one and one-quarter times the required thickness of the sides.
   - (*c*) Thickness of ends and sides—The thickness of the ends and sides may be the same provided the thickness of the cleats is not less than one and one-half times the required thickness of the sides.
   - (*d*) Length of cleats—The ends of the cleats which run across the grain of the end boards shall be one-eighth inch from the inside surface of the top and bottom.
   - (*e*) Cleats overlapped—The sides, top, and bottom shall extend over the cleats.
   - (*f*) Allowable weight of box and contents—Boxes of style 2½ may be used for any gross weight.
4. Style 3. Nailed construction having four cleats (beveled ends) at each end:
   - (*a*) Construction—The box shall be made substantially as shown for style 3, Plate 1.
   - (*b*) Thickness of ends and cleats—Either the ends or the cleats shall be three-eighths inch or more in thickness. The ends and cleats must each have a thickness at least one and one-fourth times the thickness required for the sides.
   - (*c*) Cleats overlapped—The sides, top, and bottom shall extend over the cleats.
   - (*d*) Allowable weight of box and contents—Boxes of style 3 may be used for any gross weight up to 250 pounds.
5. Style 4. Nailed construction having two cleats at each end:
   - (*a*) Construction—The box shall be made substantially as shown for style 4, Plate 1.
   - (*b*) Thickness of ends—The thickness of the ends shall not be less than three-eighths inch.
   - (*c*) Thickness of ends and cleats—The ends and cleats may be of the same thickness provided this thickness is not less than one and one-half times the required thickness of the sides.
   - (*d*) Thickness of cleats and sides—The cleats may be the same thickness as the sides, provided the thickness of the ends is not less than one and three-quarters times the required thickness of the sides.
   - (*e*) Direction of grain in cleats and ends—The cleats shall run across the grain of the end boards and shall extend within one-eighth inch of the outside surface of the top and bottom.
   - (*f*) Cleats overlapped—The sides shall extend over the cleats.
   - (*g*) Allowable weight of box and contents—Boxes of style 4 may be used for any gross weight up to 250 pounds.
6. Style 5. Nailed construction having two inside cleats at each end:
   - (*a*) Construction—The box shall be made substantially as shown for style 5, Plate 1.
   - (*b*) Thickness of ends—The thickness of the ends shall not be less than three-eighths inch.
   - (*c*) Thickness of ends and cleats—The ends and cleats may be of the same thickness provided this thickness is not less than one and one-half times the required thickness of the sides.
   - (*d*) Thickness of cleats and sides—The cleats may be the same thickness as the sides, provided the thickness of the ends is not less than one and three-quarters times the required thickness of the sides.
   - (*e*) Shape of cleats—The cleats may be either triangular or square in section, provided the cross-sectional area is not less than the cross-sectional area of the required rectangular cleats.
   - (*f*) Direction of grain in cleats and ends—The cleats shall run across the grain of the end boards and shall extend within one-eighth inch of the inside surface of the top and bottom.
   - (*g*) Ends overlapped—The sides shall extend over the ends and be flush with the outside face of the ends.
   - (*h*) Allowable weight of box and contents—Boxes of style 5 may be used for any gross weight up to 250 pounds.

7. Style 6. Locked-corner construction:
   (*a*) Construction—The box shall be made substantially as shown for style 6, Plate 1.
   (*b*) Thickness of ends and sides—The ends and sides may be of the same thickness, provided they are not less than one and one-half times the thickness required in Section IV. 1 or 3.
   (*c*) Thickness of sides—The thickness of the sides may be not less than one and one-quarter times the thickness required in Section IV. 1 or 3, provided the thickness of the ends is not less than one and three-quarters times the thickness required in Section IV. 1 or 3.
   (*d*) Allowable weight of box and contents—Style 6 boxes, having sides made from two or more pieces, may be used if the gross weight does not exceed 60 pounds.
   (*e*) Allowable weight of box and contents—Style 6 boxes, having single-piece sides of sawed lumber, may be used if the gross weight does not exceed 100 pounds.

VI. METHOD OF INSPECTION AND TEST

1. Visual and manual inspection: The boxes shall be inspected visually and manually for compliance with this specification, particularly that the lumber is well seasoned and that the construction is that shown in Plate 1 for the style of box stated in the order.
2. Measuring instruments: Suitable measuring instruments, such as a micrometer caliper, a graduated scale or rule, etc., shall be used in determining the dimensions of either the boxes or the component parts including nails and strapping.
3. Moisture content: The moisture content of the wood need not be determined by laboratory methods.
4. Strength of seals: The strength of the seals, Section III. 1 (*c*) (2), for flat nailless straps, shall be computed from the average tensile strengths of three specimens of sealed straps and three specimens of the strapping. These specimens may be any convenient length (say 18 inches). Each sealed specimen shall be prepared by fastening together the ends of two pieces of strapping with the seal applied in the usual way. The seal shall be near the middle of the specimen. A testing machine or other apparatus, such as weights, spring balance, etc., approved by the inspector shall be used to determine the strength.

VII. PACKING AND MARKING OF SHIPMENTS

1. (See Section VIII, 3.)

VIII. NOTES

1. Scope of specification: This specification applies to all empty wooden boxes, nailed and locked-corner construction, purchased by the Government for the domestic shipment of Government property by common carrier.
2. Exceptions to specifications: This specification applies to the majority of domestic shipments in wooden boxes. Exceptional commodities may require less protection, while other commodities, especially dangerous articles, may require better boxes than are specified here. In no case shall the container fall below the specifications prescribed in the Interstate Commerce Commission Regulations for the Transportation of Explosives and Other Dangerous Articles . . . (*25*) for the particular articles to which those specifications apply. (The Interstate Commerce Commission regulations apply to such articles as explosives, inflammable and corrosive liquids, compressed gases, inflammable solids, oxidizing materials, poisons, etc.)
3. Requirements for packing: Since these boxes are packed, closed, and marked by the shipper and not by the manufacturer of the box, requirements for these operations are not included in this specification (see railroad, express, and parcel post regulations).
4. Well-seasoned lumber: For box construction, well-seasoned lumber has a moisture content of 12 to 18 per cent of the weight of the wood after oven drying at 212° F. to a constant weight.
5. Applying strapping: All strapping shall be applied immediately before the box is shipped and should be drawn sufficiently tight to sink into the edges of the box. Nailless straps should be applied at right angles to the edges of the box; otherwise they are likely to become loose.

6. Orders for boxes: Orders for nailed or locked-corner boxes should give the number of boxes required, the style, the inside dimensions—length, breadth, and depth (in inches)—and the weight of the contents (in pounds).

PROPOSED UNITED STATES GOVERNMENT MASTER SPECIFICATION FOR BOXES, WOODEN, CLEATED PLYWOOD CONSTRUCTION

I. GENERAL SPECIFICATIONS

There are no general specifications applicable to this specification.

II. STYLES

1. The wooden boxes covered by this specification are of styles A, B, C, D, E, F, G, H, I, J, and K. The construction of these styles is shown in Figure 4.

2. Boxes furnished under this specification shall be of style B, D, E, or G (having 3-way corners), unless there is some special reason for using one of the other styles.

III. MATERIAL AND WORKMANSHIP

1. Material.
   (*a*) Species of wood—The principal woods used for boxes are classified as shown in Table 21.

TABLE 21.—*Classification of woods*

Group	Species
1	(Same as Group 1, p. 103.)
2	(Same as Group 2, p. 104.)
3	(Same as Group 3, p. 104.)
4	(Same as Group 4, p. 104.)

   (*b*) Seasoning—The parts shall be made from thoroughly seasoned lumber.
   (*c*) Defects—No defects shall show in the parts that will materially weaken the boxes, expose their contents to damage, or interfere with the prescribed nailing.

2. Workmanship:
   Plywood—
   (*a*) The plies shall be firmly glued together throughout the entire area in contact.
   (*b*) If a ply is made of two or more pieces, the edges shall be butted and the space between the edges shall not exceed one-fourth inch.

IV. GENERAL REQUIREMENTS

1. Plywood construction:
   (*a*) Each face of the box shall be covered with a single piece of plywood.
   (*b*) The plywood shall be made of three plies or of five plies, and the grain of each ply shall cross the grain of the adjacent ply or plies at an angle of approximately 90°.
   (*c*) The thickness of each ply shall not exceed one-twelfth inch.
   (*d*) The thickness of the plywood shall comply with the requirements given in Table 22. Occasional pieces shall not be more than 6 per cent less than the thickness specified.

TABLE 22.—*Minimum thickness of plywood for boxes of various gross weights*

Gross weight of box and contents	Thickness of plywood of woods in	
	Groups 1 and 2	Groups 3 and 4
	Inch	*Inch*
Not over 150 pounds	3/16	3/20
150 to 450 pounds	1/4	3/16
450 to 800 pounds	[illegible]/16	1/4
Over 800 pounds	3/8	5/16

2. Cleat construction:
   (*a*) Number of cleats—
      (1) Two cleats shall be used along each edge of the box, styles A and B, when the gross weight (box and contents) exceeds 150 pounds.
      (2) One cleat may be used along each edge of the box, styles C to K, inclusive, when the gross weight does not exceed 150 pounds.
   (*b*) Size of cleats—
      (1) The thickness and width of the cleats for boxes of styles A and B shall comply with the requirements given in Table 23.
      (2) Cleats on boxes of styles C to K, inclusive, shall be not less than three-fourths inch thick and of the width given in Table 23.
      (3) The cleats shall average not less than the required thickness. Occasional variations in thickness due to mismanufacture will be permitted in not over 10 per cent of the pieces, but no part of any cleat shall be less than seven-eighths the required thickness. The variation of the occasional cleat below the width specified shall not exceed one-eighth inch.

TABLE 23.—*Minimum size of cleats for boxes of styles A and B*

Gross weight of box and contents	Minimum thickness [1] of cleats for woods in—		Minimum width of cleats for all woods
	Groups 1 and 2	Groups 3 and 4	
	Inches	*Inch*	*Inches*
Not over 75 pounds	5/8	9/16	1 5/8
75 to 150 pounds	3/4	5/8	1 3/4
150 to 450 pounds	13/16	11/16	1 7/8
450 to 800 pounds	13/16	11/16	2 3/8
Over 800 pounds	1 1/8	1	2 7/8

[1] Actual, not nominal.

3. Nailing requirements:
   (*a*) The plywood panels shall be nailed or stapled to the cleats. (See fig. 4.) The nails or staples shall be driven through the plywood into and through the cleats and clinched. The nails or staples shall be staggered and spaced not more than 3 inches apart.
   (*b*) If a panel has an edge which is not cleated, the plywood along that edge shall be fastened to the cleats on an adjacent face by cement-coated nails driven through the plywood into the cleats. The nails shall be not less than 1 inch in length, and have heads not less than three-eighths inch in diameter, and be spaced not over 3 inches apart.
   (*c*) The plywood and cleats of a face shall be fastened to the cleats on the adjacent face by cement-coated nails. The size of the nails and their spacing shall comply with the requirements given in Tables 24 and 25.

TABLE 24.—*Sizes of cement-coated nails for fastening together adjacent faces*

Thickness of cleat	Size of nail [1] of type stated for nailing woods in—							
	Group 1		Group 2		Group 3		Group 4	
	Cooler and sinker	Standard box	Cooler and sinker	Standard box	Cooler and sinker	Standard box	Cooler and sinker	Standard box
	Penny	*Penny*	*Penny*	*Penny*	*Penny*	*Penny*	*Penny*	*Penny*
5/8 inch	7	7	6	6	6	6	5	5
3/4 inch	8	8	8	8	7	7	6	6
25/32 to 7/8 inch	9	9	8	8	7	7	7	7
1 1/8 inches	10	-------	10	-------	9	-------	9	-------

[1] Table 12 gives the length and gage of the three kinds of nails.

TABLE 25.—*Spacing of cement-coated cooler and sinker nails for fastening together adjacent faces*

Gross weight of box and contents	Spacing
	Inches
Not over 75 pounds	6
75 to 150 pounds	5
150 to 450 pounds	4
450 to 800 pounds	3
Over 800 pounds	2

Boxes nailed with standard cement-coated box nails shall have approximately 10 per cent more nails than boxes nailed with cooler and sinker cement-coated nails.

Two nails shall be driven through each end of a cleat into the cleat on the adjacent face, except that when the gross weight does not exceed 150 pounds one nail may be used.

V. DETAIL REQUIREMENTS

Plywood boxes shall be constructed as illustrated in Figure 4 for the style ordered.

In no case shall the container fall below the specifications prescribed in the Interstate Commerce Commission Regulations for the Transportation of Explosives and Other Dangerous Articles . . . (*25*) for the particular articles to which those specifications apply. (The Interstate Commerce Commission regulations apply to such articles as explosives, inflammable and corrosive liquids, compressed gases, inflammable solids, oxidizing materials, poisons, etc.).

VI. METHOD OF INSPECTION AND TEST

1. Visual and manual inspection.—The boxes shall be inspected visually and manually for compliance with these specifications, particularly that the lumber is well seasoned and that the construction is that shown in Figure 4 for the style of box ordered.

2. Measuring instruments.—Suitable measuring instruments, such as a micrometer caliper, graduated scale or rule, etc., shall be used in determining the dimensions of either the boxes or the component parts, including nails.

3. Moisture content.—The moisture content of the wood need not be determined by laboratory methods.

VII. PACKING AND MARKING OF SHIPMENTS

1. (See Section VIII, 3.)

VIII. NOTES

1. Scope of specification.—This specification applies to all empty wooden boxes, cleated plywood construction, purchased by the Government for the domestic shipment of Government property by common carrier.

2. Exceptions to specifications.—This specification applies to the majority of shipments in wood boxes. Exceptional commodities may require less protection while other commodities, especially dangerous articles, may require better boxes than are specified here.

3. Requirements for packing.—Since these boxes are packed, closed, and marked by the shipper and not by the manufacturer of the box, requirements for these operations are not included in this specification (see railroad, express, and parcel post regulations).

4. Well-seasoned lumber.—For box construction, well-seasoned lumber has a moisture content of from 12 to 18 per cent of the weight of the wood after oven drying at 212° F. to constant weight.

5. Three-way corners.—In a box having 3-way corners, the sides overlap the ends, the ends overlap the top and bottom, and the top and bottom overlap the sides.

6. Orders for boxes.—Orders for plywood boxes should give the number of boxes required, the style, the inside dimensions—length, breadth, and depth (in inches)— and the weight of the contents (pounds).

7. Selection of style.—The selection of the style of box depends largely on the nature and weight of the commodity and how the commodity is to be supported. Types B, D, E, and G (having 3-way corners) are all satisfactory if the boxes are not to be opened for inspection. If the boxes are to be opened and reclosed, types A and K would, in general, be preferable. The full-cleated types A and B are the strongest and most suitable for heavy commodities if the weight may be applied over the entire area of any of the faces.

PROPOSED UNITED STATES GOVERNMENT MASTER SPECIFICATION FOR BOXES, FIBER, CORRUGATED

I. GENERAL SPECIFICATIONS

There are no general specifications applicable to this specification.

II. STYLES

1. This specification covers the usual styles of corrugated fiber boxes without wooden frames, as follows:
   - (*a*) One piece—
     - Style 1—1-piece box.
   - (*b*) Two piece—
     - Style 2—half-slotted box.
     - Style 3—design box.
     - Style 4—telescope box (design style).
     - Style 5—telescope box (taped-corner style).
   - (*c*) Three piece—
     - Style 6—triple-slide box.
2. The construction of these boxes is shown in Figure 8.

III. MATERIAL AND WORKMANSHIP

1. Material:
   - (*a*) The box shall be made of either double-faced corrugated board of or double-wall board.
   - (*b*) Double-faced corrugated board shall have one corrugated sheet between two flat facings. The corrugations shall be securely glued to the facing over all of the surfaces in contact.
   - (*c*) Double-wall board shall have one flat filler between two corrugated sheets and one flat facing on each outer surface. The corrugations shall be securely glued to the filler sheet and to the facings over all of the surfaces in contact.
   - (*d*) Facings and liners shall comply with the requirements in Table 26.
   - (*e*) Corrugated sheets may be strawboard, chestnut fiber board, pine wood fiber board, or other material which has been demonstrated to give equal service. The sheet before corrugating shall be calendered to a uniform thickness of not less than 0.009 inch. The sheet shall neither crack nor break when corrugated. There shall be not less than 32 corrugations per foot. There are no bursting strength requirements for corrugated sheets.
   - (*f*) The outer facing of each board shall be waterproofed except the board for the inner slide of style 6 boxes.
   - (*g*) Metal fasteners (rivets, staples, and stitching wire) shall be steel, treated to resist rust, and when subjected to conditions of use shall not show cracks or other evidence of weakness.
   - (*h*) Pads, when required by transportation rules for filling the space between the ends of inner flaps of style 1 and style 2 boxes, shall be made of the same board that is used in the box.
   - (*i*) Gummed tape—
     - (1) Gummed tape for boxes made of board, items 1 and 2, Table 26, may be either paper or cloth. The tape shall be not less than 2 inches wide, shall have a bursting strength of not less than 60 points, and shall be uniformly coated with glue.
     - (2) Gummed tape for boxes made of board, items 3, 4, and 5, Table 26, shall be cloth. The tape shall be not less than 3 inches wide, shall have a bursting strength of not less than 80 points, and shall be uniformly coated with glue.

2. Workmanship: All corrugated board parts shall be cut square and shall be the required size. They shall be creased and slotted so that in the assembled box the parts fit closely without undue binding. Further, all creasing shall be performed so as not to cause surface breaks in the board, either at the time of creasing or when filling and sealing the box, nor any separation of the facings or fillers from the corrugated sheet. No flap shall project beyond the edge of the box.

IV. GENERAL REQUIREMENTS

1. Corrugated fiber board: The corrugated board of the box shall comply with Table 26.

TABLE 26.—*Requirements for corrugated fiber board*

Item No.	Gross weight of box and contents not over—	Size of box (length, breadth, and depth added) not over—	Kind of board	Minimum thickness of board		Minimum bursting strength of board	
				Facing or filler	Board	Facing	Board
	Pounds	*Inches*		*Inch*	*Inch*	*Points*	*Points*
1	40	60	Double-faced	0.016	3/16	85	175
2	65	65	do	.016	3/16	100	200
3	90	70	do	.030	3/16	135	275
4	65	65	Double-wall	.016	3/8	85	200
5	90	70	do	.016	3/8	[1] 85	275

[1] Bursting strength requirement also applies to filler in item No. 5.

2. Metal fastenings:
   (*a*) Metal fastenings may be rivets, staples, or stitching wire.
   (*b*) Staples or stitches shall be not less than one-half inch wide, shall pass through all the pieces to be fastened, and shall be clinched.
   (*c*) Rivets of an equivalent strength and holding power may be substituted for wire staples or stitches.
3. Body joints:
   (*a*) Body joints shall be butt, spliced, or lapped.
   (*b*) Butt joints shall have the edges of the board meet and shall be fastened with tape glued along the entire length of the joint.
   (*c*) Spliced joints shall have the corrugated portion of one edge (and the filler, if any) removed and the inner and outer facings spliced over the adjoining edge. The overlap shall be not less than 1 inch and both facings shall be securely glued.
   (*d*) Lapped joints shall have the edges overlap not less than 1½ inches and shall be secured with metal fasteners spaced not more than 2½ inches.
4. Body piece: For styles 1, 2, and 6, the body piece shall be made from one piece and shall have the joint along one of the four edges perpendicular to the opening.
5. Covers: Separate covers shall be made from one piece of corrugated board. Corner joints may be butt, spliced, or lapped as defined for body joints except that if lapped joints are used, each joint shall have not less than two metal fasteners.

V. DETAIL REQUIREMENTS

1. Style 1, 1-piece box:
   (*a*) This box shall be made from one piece, slotted and scored to form a body piece having four flaps for closing each of two opposite faces.
   (*b*) The width of each of the inner flaps shall be not less than one-half its length measured along its creased edge.
   (*c*) The two outer flaps when in the closed position shall either meet at the middle of the face or shall overlap not less than 1 inch.
   (*d*) The body joint shall be butt, spliced, or lapped.
2. Style 2, half-slotted box:
   (*a*) The body of this box shall have four flaps which close one face as in style 1, and a separate cover shall fit over the opposite face.
   (*b*) All joints shall be butt, spliced, or lapped.

3. Style 3, design box:
   (*a*) The body of this box shall have a continuous (undivided) bottom and sides. The depth of the cover shall be less than the depth of the body.
   (*b*) All body joints shall be lapped.
   (*c*) All cover joints shall be butt, spliced, or lapped.
4. Style 4, telescope box (design style): This box shall be similar to style 3, except that the body and cover shall have the same depth.
5. Style 5, telescope box (taped-corner style): This box shall be similar to style 4, except that the joints in the body and cover shall be butt joints.
6. Style 6, triple-slide box: This box shall be made of three rectangular body pieces each having four faces. All joints shall be butt or spliced joints. The pieces shall slide together snugly and there shall be two thicknesses of corrugated board on each of the six faces of the box.

VI. METHOD OF TESTING

1. Bursting-strength apparatus: The bursting-strength test consists essentially in clamping the fiber board between two surfaces having concentric circular apertures 1.24 inches in diameter and then applying hydraulic pressure through a fluid to a rubber diaphragm secured to one of the circular apertures. The pressure required to burst the board is recorded by means of a pressure gauge calibrated to record pounds per square inch and is reported in "points." For detailed information, see Official Paper Testing Methods of the Technical Association of the Pulp and Paper Industries (*19, v. 83, p. 51–55*).
2. Bursting-strength method: The bursting strength of corrugated fiber board or gummed tape shall be determined as follows:
   (*a*) In testing, the board or tape shall be clamped firmly in the machine to prevent slipping; the wheel of the testing machine shall be turned at a uniform speed of approximately two revolutions per second. The corrugations of the corrugated board must not be crushed when clamped in the testing machine.
   (*b*) Six punctures shall be made, three from each side of the board. For the board to comply with this specification, not more than one puncture shall fall below the strength specified in Table 26.
   (*c*) If the board fails to pass the test as specified in VI.2 (*b*), then a retest may be made consisting of 24 punctures, 12 from each side of the board. If not more than four punctures fall below the strength requirements, the board complies with this specification.
   (*d*) The punctures should preferably be made on the specimen after it has come to moisture equilibrium with an atmosphere of 65 per cent relative humidity at a temperature of 70° F.
   (*e*) When testing double-faced corrugated board, if a puncture gives two "pops," the result shall be disregarded and another puncture made.
3. Strength of joints: The strength of the joints shall be observed by grasping a body or a cover in the hands, one each side of the joint, and pulling until the joint ruptures. Failure shall occur in the board, not in the fastenings nor by separation of the glued surfaces.
4. (*a*) Visual and manual inspection: The boxes shall be inspected visually for compliance with this specification, particularly that the construction is that shown in Figure 8, for the style of box stated in the order.
   (*b*) The fit of the flaps, slides, and cover shall be determined by assembling and disassembling the box.
5. Measuring instruments: Suitable measuring instruments such as a graduated scale or rule shall be used to determine the dimensions.

VII. PACKING AND MARKING OF SHIPMENTS

1. (See Section VIII, 4.)

VIII. NOTES

1. Scope of specification: This specification applies to all empty corrugated fiber boxes purchased by the Government for the domestic shipment of Government property by common carrier.
2. Exceptions to specifications: This specification applies to the majority of shipments in fiber boxes. Exceptional commodities may require less protection while other commodities, especially dangerous articles, may require better boxes than are here specified. In no case should the quality of the

container fall below the specifications prescribed in the Interstate Commerce Commission Regulations for the Transportation of Explosives and Other Dangerous Articles . . . (*25*) for the particular articles to which those specifications apply. (The Interstate Commerce Commission regulations apply to such articles as explosives, inflammable and corrosive liquids, compressed gases, inflammable solids, oxidizing materials, poisons, etc.)

3. Variations within styles: It is not intended to prevent the use of ordinary variations within styles, such as different lengths of closing flaps. Such variations are subject to the discretion of the department ordering the boxes. The design of special styles of corrugated fiber containers is not covered by this specification.
4. Requirements for packing: Since these shipping containers are packed, closed, and marked by the shipper and not by the manufacturer of the container, requirements for these operations are not included in this specification (see railroad, express, and parcel post regulations).
5. Selection of style: The following information dealing with the six styles of corrugated fiber boxes included in this specification may be helpful in making a satisfactory selection:
   - (*a*) Style 1, 1-piece box.—This style of box is often called a "slotted carton." It is probably in more general use than any other style considered in this specification, and is used for shipping a wide variety of materials. It is shipped flat, takes up but little room in storage, and is set up and sealed by the shipper. For freight and express shipments, the flaps must be sealed according to rules of the transportation companies.
   - (*b*) Style 2, half-slotted box.—This box differs from style 1 in the fact that it has a separate cover which makes it a convenient shelf package as well as shipping container. It is also convenient to cut down its depth to change the size of the box. The flaps must be sealed in the same manner a provided for style 1. Express rules require tying with specified materials, while freight rules offer several optional methods of sealing.
   - (*c*) Style 3, design box.—The body part of this box is ordinarily folded flat for shipment and is set up by the shipper with a hand stapling device. The covers are usually finished with tape on the corners ready for use and are shipped either set up or nested. The cover may also be made the same as the body if it is desired to have it fold flat. This box was originally intended for express shipments where something stronger than the ordinary cardboard carton was desired, but it is also used for freight. For express shipments, it must be closed by tying in a prescribed manner. Freight rules provide several optional methods of closing, some of which involve gluing or sealing with tape.
   - (*d*) Style 4, telescope box (design style).—Both top and bottom of this box may be shipped and stored flat to be set up by the user. It is usually used when a shallow container is desired, as for books, pictures, and lithographic cutouts. Because of the added thicknesses of material, the sides and ends provide more cushioning protection than the top and bottom. For freight shipments, this box must be tied and sealed in a prescribed manner. For express, the rules are somewhat similar except that seals are not required.
   - (*e*) Style 5, telescope box (taped-corner style).—This box is shipped to the user set up and ready for use. It is used for the same materials as style 4 and the same closing requirements apply.
   - (*f*) Style 6, triple-slide box.—This style has two thicknesses of material on all faces, thus offering the same cushioning protection on all sides. It is used for freight, express, and parcel post shipments and is used in a large number of sizes. The closing requirements for this style of box are fairly simple and easy to comply with.
6. Orders for boxes: Orders for corrugated fiber boxes should give the number of boxes required, the style, the inside dimensions—length, breadth, depth (in inches)—and the weight of the contents (pounds).

PROPOSED UNITED STATES GOVERNMENT MASTER SPECIFICATION FOR BOXES, FIBER, SOLID

I. GENERAL SPECIFICATIONS

There are no general specifications applicable to this specification.

II. STYLES

1. This specification covers the usual styles of solid fiber boxes without wooden frames as follows:
   (*a*) One piece—
   Style A, 1-piece box.
   (*b*) Two piece—
   Style B, half-slotted box.
   Style C, design box.
   Style D, telescope box.
2. The construction of these boxes is shown in Figure 9.
3. The style of box shall be stated in the invitation for bids.

III. MATERIAL AND WORKMANSHIP

1. Material:
   (*a*) The box shall be made of fiber board consisting of three or more plies of either fiber or pulp board firmly glued together.
   (*b*) No ply shall be less than 0.016 inch thick.
   (*c*) The outer ply shall be waterproofed.
   (*d*) Pads, when required by transportation rules for filling the space between the ends of inner flaps of style A and style B boxes, shall be made of the same board as the box.
   (*e*) Metal fasteners (rivets, staples, and stitching wire) shall be of steel, treated to resist rust, and when subjected to conditions of use shall not show cracks or other evidence of weakness.
2. Workmanship:
   (*a*) All fiber board parts shall be cut square and shall be of the required size. They shall be creased and slotted so that in the assembled box the parts fit closely without undue binding. All creasing shall be performed so as not to cause surface breaks in the board, either at the time of creasing, or when filling and sealing the box. No flap shall project beyond an edge of the box.

IV. GENERAL REQUIREMENTS

1. Fiber board: The fiber board in the box shall comply with Table 27.

TABLE 27.—*Thickness and bursting strength of solid fiber board*

Maximum weight of box and contents	Maximum size of box, length, breadth, and depth added	Minimum thickness of board	Minimum bursting strength of board
Pounds	*Inches*	*Inch*	*Pounds*
40	60	0.060	175
65	65	.080	200
90	70	.100	275

2. Metal fastenings:
   (*a*) Metal fastenings may be rivets, staples, or stitching wire.
   (*b*) Staples, or stitches shall be not less than one-half inch wide, shall pass through all the pieces to be fastened, and shall be clinched.
   (*c*) Rivets of an equivalent strength and holding power may be substituted for wire staples or stitches.

3. Body joints:
   (*a*) The joint is that part of the box where the box manufacturer joins the body of the box together.
   (*b*) For styles A and B the body piece shall be made from one piece and shall have the joint along one of the four edges except that, if the grain (machine direction) of the fiber board is parallel to the joint, the body piece may have two joints, one at each of two diagonally opposite edges.
   (*c*) At each joint in the body piece the fiber board shall overlap not less than $1\frac{1}{2}$ inches and be secured either by metal fasteners or by glue.
   (*d*) If metal fasteners are used, they shall be spaced not over $2\frac{1}{2}$ inches and the distance between the outer fasteners and the end of the joint shall not exceed 1 inch. If the length of the joint exceeds 18 inches, an additional fastener shall be used about 1 inch from each end.
   (*e*) If glue is used, it shall secure firmly the entire surface of the joint. If the length of the joint exceeds 18 inches, a metal fastener shall be used about 1 inch from each end.
4. Covers: Separate covers shall be made from one piece of fiber board, and each corner joint shall be fastened with not less than two metal fasteners.

V. DETAIL REQUIREMENTS

1. Style A, 1-piece box:
   (*a*) This box shall be made from one piece, slotted and scored to form a body piece having four flaps for closing each of two opposite faces.
   (*b*) The width of each of the inner flaps shall not be less than one-half its length measured along its creased edge.
   (*c*) The two outer flaps when in the closed position shall either meet at the middle of the face or shall overlap not less than 1 inch.
2. Style B, half-slotted box: The body of this box shall have four flaps which close one face as in type A. A separate cover shall fit over the opposite face.
3. Style C, design box: The body of this box shall have a continuous (undivided) bottom and sides. The depth of the separate cover shall be less than the depth of the body.
4. Style D, telescope box: This box shall be similar to style C except that the body and the cover shall have the same depth.

VI. METHODS OF TESTING

1. Bursting-strength apparatus: The bursting-strength test consists essentially in clamping the fiber board between two surfaces having concentric circular apertures 1.24 inches in diameter and then applying hydraulic pressure through a fluid to a rubber diaphragm secured to one of the circular apertures. The pressure required to burst the board is recorded by means of a pressure gauge calibrated to record pounds per square inch and is reported in "points." For detailed information see Official Paper Testing Methods of the Technical Association of Pulp and Paper Industries (*19, v. 83, p. 51–55*).
2. Bursting-strength method: The bursting strength of fiber board shall be determined as follows:
   (*a*) In testing, the board shall be clamped firmly in the machine to prevent slipping, the wheel of the testing machine shall be turned at a uniform speed of approximately two revolutions per second.
   (*b*) Six punctures shall be made, three from each side of the board. For the board to comply with this specification not more than one puncture shall fall below the strength requirements.
   (*c*) If the board fails to pass the test as specified in VI. 2 (*b*), then a retest may be made consisting of 24 punctures, 12 from each side of the board. If not more than four punctures fall below the strength requirements, the board complies with this specification.
   (*d*) The punctures should preferably be made on the board after it has come to moisture equilibrium in an atmosphere of 65 per cent relative humidity at a temperature of 70° F.
3. Waterproofing: The waterproofing of the board shall be determined by the decrease in bursting strength after the board has been exposed at ordinary room temperature to a column of water 3 inches high and not less than 4 inches in diameter for three hours. When making the test the clamp shall be centered so as not to cover any portion of the board which has

not been exposed to the column of water. The bursting strength shall be determined in accordance with VI. 1 and 2. Boards when subjected to this test shall have at least 50 per cent of the bursting strength determined by VI. 2.

4. Strength of joints: The strength of the joints shall be observed by grasping a body or a cover in the hands on each side of the joint and pulling until the joint ruptures. Failure shall occur in the fiber board, not in the fasteners nor by separation of the glued surfaces.

5. (*a*) Visual and manual inspection: The boxes shall be inspected visually and manually for compliance with this specification, particularly that the construction is that shown in Figure 9 for the style of box stated in the order.

   (*b*) The fit of the flaps, slides, and cover shall be determined by assembling and dissembling the box.

6. Measuring instruments: Suitable measuring instruments such as a graduated scale or rule shall be used to determine the dimensions.

VII. PACKING AND MARKING OF SHIPMENTS

1. (See Section VIII, 4.)

VIII. NOTES

1. Scope of specification: This specification applies to all empty solid fiber boxes purchased by the Government for the domestic shipment of Government property by common carrier.

2. Exceptions to specifications: This specification applies to the majority of shipments in fiber boxes. Exceptional commodities may require less protection while other commodities, especially dangerous articles, may require stronger boxes than are here specified. In no case should the quality of the container fall below the Interstate Commerce Commission Regulations for the Transportation of Explosives and Other Dangerous Articles . . . (*25*) for the particular articles to which those specifications apply. (The Interstate Commerce Commission regulations apply to such articles as explosives, inflammable and corrosive liquids, compressed gases, inflammable solids, oxidizing materials, poisons, etc.)

3. Variations within styles: It is not intended to prevent the use of ordinary variations within styles, such as different lengths of closing flaps. Such variations are subject to the discretion of the department ordering the boxes. The design of special styles of solid fiber boxes is not covered by this specification.

4. Requirements for packing: Since these boxes are packed, closed, and marked by the shipper and not by the manufacturer of the boxes, requirements for these operations are not included in this specification (see railroad, express, and parcel post regulations).

5. Selection of style: The following information dealing with the four styles of solid fiber boxes included in this specification may be helpful in making a satisfactory selection.

   (*a*) Style A, 1-piece box—This style box is often called a "slotted carton." It is probably in more general use than any of the styles considered in this specification and is used for shipping a wide variety of of materials. It is shipped flat, takes up but little room in storage, and is set up and sealed by the shipper. For freight and express shipments, the flaps must be sealed according to rules of the transportation companies.

   (*b*) Style B, half-slotted box, 2-piece—This box differs from style A in that it has a separate cover which makes it a convenient shelf package as well as a shipping container. The body may be cut down decreasing the depth which is a convenient way to change the size of the box. The flaps must be sealed in the same manner as provided for style A. Express rules require tying with specified materials, while freight rules offer several optional methods of sealing.

   (*c*) Style C, design box—The body part of this box is ordinarily folded flat for shipment and is set up by the shipper with a hand stapling device. The covers may also be shipped flat and be made up by the shipper. This box is used for both express and freight shipments. Freight rules offer optional methods of sealing, depending on the cover construction. Express rules are somewhat different from freight rules for methods of sealing this box.

(*d*) Style D, telescope box—This style of box is often used when a shallow container is desired, such as for books, pictures, and lithographic cut-outs. For freight shipments, this box must be tied and sealed in a prescribed manner. For express, the rules are somewhat similar except that seals are not required.

6. Orders for boxes: Orders for solid fiber boxes should give the number of boxes required, the style, the inside dimensions—length, breadth, and depth (in inches)—and the weight of the contents (pounds).

PROPOSED UNITED STATES GOVERNMENT MASTER SPECIFICATION FOR WIRE-BOUND BOXES[21]

I. GENERAL SPECIFICATIONS

There are no general specifications applicable to this specification.

II. STYLES

This specification covers all common styles of wire-bound boxes.

(Definitions of the wire-bound box and its parts are given under "Notes," paragraph 1 (a).)

III. MATERIAL AND WORKMANSHIP

1. Material:

(*a*) Lumber—

(1) Seasoning—All pieces shall be made of well-seasoned lumber.

(2) Defects—The pieces shall show no defects that materially weaken them, expose the contents of the box to damage, or interfere with the prescribed stapling or nailing.

Each cleat and batten shall be free from knots and from cross grain which runs across it within a distance equal to one-half its length.

In the thin boards of the sides, top, bottom, and ends large knots at the ends of the pieces, slanting shakes, and decayed wood are especially objectionable.

(3) Species of wood—The principal woods used for boxes are classified as follows:

Group	Species
1	(Same as Group 1, p. 103.)
2	(Same as Group 2, p. 104.)
3	(Same as Group 3, p. 104.)
4	(Same as Group 4, p. 104.)

(*b*) Binding wire—The binding wire shall be of a quality that will make an efficient closure which can not easily be opened and reclosed without giving evidence of the operation.

(*c*) Staple wire—The staple wire shall be of such a quality and hardness as to produce well-formed staples that will drive properly.

(*d*) Nails—Cement-coated cooler or sinker nails of the dimensions given in Table 28 shall be standard for wire-bound boxes.

TABLE 28.—*Dimensions of standard cement-coated cooler and sinker nails*

Size	Length	Diameter		Size	Length	Diameter	
	Inches	*Gage No.*[1]	*Inch*		*Inches*	*Gage No.*[1]	*Inch*
Twopenny	1	16	0.0625	Sixpenny	1 7/8	13	0.0915
Threepenny	1 1/8	15½	.0672	Sevenpenny	2 1/8	12½	.0985
Fourpenny	1 3/8	14	.0800	Eightpenny	2 3/8	11½	.1130
Fivepenny	1 5/8	13½	.0857	Ninepenny	2 5/8	11½	.1130

[1] Washburn & Moen.

If nails less than 1 inch long are required, standard cement-coated barrel nails of the following sizes are suggested: Three-fourths inch by 15½ gage, and seven-eighths inch by 14½ gage.

[21] Prepared by the Forest Products Laboratory in cooperation with the Wirebound Box Manufacturer's Association. The specification is tentative and subject to revision before being adopted as standard.

(*e*) Reinforcing wires—
(1) Either wires, having a tensile strength of not less than 60,000 pounds per square inch, or "special annealed" flat metal straps may be used. (Special annealed strapping has an average tensile strength of approximately 84,000 pounds per square inch.)
(2) Closures or seals used to hold together the ends of the reinforcing wires or straps shall have not less than 60 per cent of the tensile strength of the wire or strap.

2. Workmanship:
(*a*) Fabrication—All parts of the box shall be cut to size and the box shall be fabricated in accordance with good commercial practice. The separate sections of the mat shall be spaced such a distance from each other that, when assembled, the thin boards and wires shall fold in such a manner as to give enough tension to the wires to make a tight corner.
(*b*) Variation in thickness of thin boards—
(1) The thin boards in each box shall average not less than the specified thickness. No part of any piece shall be less than seven-eighths the specified thickness.
(2) An allowance not greater than 5 per cent below the thickness of veneer specified shall be made for shrinkage, it being assumed that the material was cut full thickness when green.
(3) Thicknesses of resawn lumber are specified for material S1S or S2S. If neither side is surfaced, one sixty-fourth inch thicker material must be used.
(*c*) Variations in dimensions of cleats—
(1) A variation of not more than one-sixteenth inch in one or one-thirty-second inch in each dimension below the specified cross-sectional dimensions of the cleat will be permitted.
(*d*) Driving of staples—
(1) The staples on the wires which are coincidental with cleats shall be driven home astride the binding wires, through the thin boards into the cleats. The points of the staples may go through the cleats and clinch but must not protrude from the cleats.
(2) The staples on intermediate wires shall be driven astride the binding wires, through the thin boards, and shall be firmly clinched.
(3) The staples or nails securing the end boards to the inside of the cleats and battens shall be driven flush with the surface of the wood. Occasional overdriving of staples or nails will be permitted, but the head of no staple or nail shall protrude or be overdriven more than one-eighth the thickness of the piece.
(*e*) Application of binding wires—Each binding wire shall be continuous once around the box with the ends of sufficient length to be securely twisted at one side; provided, that wires not less than No. 12 gage may be in sections, if there are loops at the connection end of each section one of which may be passed through the other and bent back securely against the box.

IV. GENERAL REQUIREMENTS

See detail requirements.

V. DETAIL REQUIREMENTS

1. Sides, top, and bottom:
(*a*) Thickness—The thin boards of the sides, top, and bottom shall be not less than the thicknesses indicated by the appropriate design chart, Figures 30, 31, 32, and 33.
(*b*) Method of determining thickness of thin boards—To determine the thickness of thin boards, proceed as follows: First, select the chart pertaining to the species of material under consideration. Start with the weight of contents. Follow the horizontal weight line from the scale at the left border of the chart to its intersection with the vertical

line from the scale at the lower border representing the average of width and depth of box. At or above this intersection is the line representing the thickness of material required.

(*c*) Minimum width of thin boards—Thin boards less than 2 inches wide at either end shall not be used.

2. Ends:

(*a*) Thickness—The thickness of the thin boards (if any) in the ends shall be not less than that of the sides, top, and bottom.

3. Cleats:

(*a*) Dimensions—Cleats shall be designated as light (thirteen-sixteenth inch thick by nine-sixteenth inch wide), standard (thirteen-sixteenth inch thick by seven-eighth inch wide), and heavy (1⅛ inch thick by thirteen-sixteenth inch wide). The thickness of a cleat is defined as the dimension parallel to the grain direction of the thin boards in the sides, top, and bottom.

4. Battens:

(*a*) Thickness—Battens shall be the same thickness, measured in the same direction, as the cleats.

(*b*) Arrangement—Most of the common arrangements of battens are shown in Figure 7, page 27.

(*c*) Purpose of battens—Battens may be required for one or both of two principal purposes; (1) to reinforce the thin boards of the ends, and (2) to reinforce the cleats.

(1) End reinforcement—When the thin boards of the ends are of the same thickness as the sides, top, and bottom, they shall be reinforced with battens across the grain so spaced that the distance between battens or between cleats and battens is not greater than as follows: (These battens shall be not less than thirteen-sixteenth inch in width.)

For ⅛-inch ends, 10 inches.
For ⅙ or 3/16-inch ends, 12 inches.
For 7/32 or ¼-inch ends, 14 inches.
For 5/16-inch ends, 16 inches.
For ⅜-inch ends, 18 inches.

Liners not thinner than the ends may be substituted for battens on ends 3/16 inch or less in thickness. The liners adjacent to the side cleats shall be not less in width than the cleats. Intermediate liners shall be not less than 3 inches wide. If liners inside the end interfere with the contents of the box they may be positioned between the end and cleats (on the outside of the end but inside the cleats).

(2) Cleat reinforcement—No reinforcement is required for cleats of the species and sizes indicated below if the weight of contents is not greater than that shown in Table 29.

TABLE 29.—*Weight of contents permitted in boxes without cleat reinforcement*

Wood in cleats	For light cleats (13/16 by 9/16 inch)	For standard cleats (13/16 by ⅞ inch)	For heavy cleats (1⅛ by 13/16 inch)
	Pounds	*Pounds*	*Pounds*
Group 1	29	98	231
Group 2	38	126	300
Group 3	50	169	400
Group 4	69	234	547

Reinforcement for standard cleats of the species and for the weights of contents indicated shall be not less than given in Table 30. (The battens shall be not less than 1⅛ inches in width.)

TABLE 30.—*Reinforcements required for standard cleats of boxes carrying various weights of contents*

Wood in cleats	Weight of contents, pounds	Cleat reinforcement
Group 1	98 to 23t	(1) Battens adjacent to and parallel with the short cleats, or (2) one reinforcing wire over faces of widest dimension.
Group 2	126 to 300	
Group 3	169 to 400	
Group 4	234 to 547	
Group 1	231 to 450	(1) Battens adjacent to and parallel with all cleats, or (2) battens adjacent to and parallel with the short cleats and one reinforcing wire over faces of widest dimension, or (3) two reinforcing wires (one over ends and sides and one over ends, top, and bottom).
Group 2	300 to 585	
Group 3	400 to 780	
Group 4	547 to 1,068	
Group 1	Over 450	Battens adjacent to and parallel with all cleats, and two reinforcing wires (one over ends and sides and one over ends, top, and bottom).
Group 2	Over 585	
Group 3	Over 780	
Group 4	Over 1,068	

5. Stapling of sides, top, and bottom:
   (*a*) The spacing of staples is defined as the average distance between centers of staples.
   (*b*) Staples on wires which are coincidental with cleats made of Groups 3 and 4 woods shall be of not less than the gauge and length shown below and shall be spaced not farther apart than as indicated below:

For thin boards one-eighth inch in thickness—

Gage	Length (inches)	Spacing (inches)
16	7/8	2

For thin boards more than one-eighth inch to and including one-fourth inch in thickness—

Gage	Length (inches)	Spacing (inches)
16	1 1/8	2
16	1	1 3/4
16	7/8	1 1/2
15	1	2

For thin boards more than one-fourth inch to and including three-eighth inch in thickness—

Gage	Length (inches)	Spacing (inches)
16	1 1/4	2
16	1 1/8	1 1/2
15	1	1 1/2
14	1	1 3/4

   (*c*) At least two staples must be placed in each end of each thin board.
   (*d*) When cleats are made of woods of Groups 1 and 2, the staples shall be spaced at least one-fourth inch closer than as specified for cleats of Groups 3 and 4 woods.
   (*e*) The staples on intermediate wires shall be not smaller than as follows:

For thin boards one-eighth inch in thickness—18 gage by three-eighth inch long.

For thin boards more than one-eighth inch to and including seven-thirty-seconds inch in thickness—18 gage by seven-sixteenths inch long.

For thin boards more than seven thirty-seconds of an inch, to and including three-eighths of an inch in thickness—18 gage by nine-sixteenths of an inch long.

   (*f*) The staple nearest each corner of the box shall be not more than 1 1/2 inches from the end of the cleat.

6. Fastenings of ends:
   (*a*) Staples or cement-coated nails used to fasten the ends to the cleats and battens shall be not smaller than 16 gage, and shall be long enough to penetrate at least three-fourths the thickness of the cleats or battens. If these nails or staples extend through the cleat or batten they shall be clinched.

(*b*) The average space between staples or nails in cleats or battens extending across the grain of the ends shall be not more than 2½ inches beginning not more than 1¾ inches from the open face of the box, and in battens extending along the grain of the ends the space between nails or staples shall be not more than 6 inches.

(*c*) Staples used to fasten the liners to the ends shall be long enough to clinch securely. In the intermediate liners the staples shall be staggered so as to have two rows, and the distance between staples in each row shall be not more than 3 inches.

7. Auxiliary fastenings:

(*a*) One sixpenny nail for light cleats and one or more sevenpenny nails for standard and heavy cleats shall be driven through the thin board and cleat into each end of each batten that comes in end contact with a cleat.

(*b*) Battens required adjacent to and parallel with the standard cleats shall not only be secured to the thin boards of the ends, as indicated in paragraph 6, but shall have sevenpenny nails, spaced not more than 5 inches apart, driven through the thin boards and cleats into the battens.

Longer nails than those specified in paragraph 7 (*a*) and (*b*) may be used provided they are not of larger gage.

8. Thick ends:

(*a*) As indicated by paragraph 4 (*c*) (1) thicker ends without battens may be used in some cases in place of the thinner ends with battens. For example, if the ends are 18 inches long between the cross cleats and the thin boards are less than three-eighths of an inch in thickness one batten (style A) is required, whereas three-eighths-inch ends without battens (style T) could be used.

(*b*) If the sides, top, and bottom of the box are fastened to ends having thicknesses of not less than that shown in Table 31, with nails of the sizes indicated and spaced not more than 2½ inches apart, battens may be dispensed with.

TABLE 31.—*Thicknesses of ends, sides, tops, and bottoms, and nailing that may be used without end reinforcements*

Required thickness of thin boards	Thickness of ends without battens	Size of nailing of sides, top, and bottom to ends [1]
	Inch	*Penny*
3/16-inch or less	3/8	None required.
Over 3/16 to 1/4 inch	1/2	4
Over 1/4 to 5/16 inch	5/8	5
Over 5/16 to 3/8 inch	3/4 to 7/8	6

[1] For fastening of ends to cleats see par. 6 (*a*) and (*b*).

9. Binding wires:

(*a*) Number and gage—The binding wires shall be of not less than the number and gage (Washburn & Moen) indicated by the design charts, Figures 30, 31, 32, and 33.

(*b*) Method of determining number and gage of binding wires. The wire curves are the same on all four of the charts. To determine the number and size of wires to use, start with the weight of the contents. Follow the horizontal weight line to its intersection with the curve representing the gage of wire chosen. At or to the right of this intersection is the vertical line representing the number of wires required.

For many weights there is a choice of gages and number of wires that may be used. The dimensions of the box must be kept in mind, however, and also the fact that the wires can not be spaced closer than 4 inches to each other, and the notes in paragraph 9 (*c*) regarding maximum spacing of wires should be observed. These points may prove the determining factors in a given case where a greater range of selection is otherwise indicated by the chart.

(c) Maximum spacing of binding wires—Unless otherwise specified, the binding wires must be uniformly spaced, and the distance between the wires shall be not greater than as follows:

For 1/8-inch material, 5 inches.
For 1/6 and 3/16 inch material, 6 inches.
For 7/32 and 1/4 inch material, 7 inches.
For 5/16-inch material, 8 inches.
For 3/8-inch material, 9 inches.

It is often advantageous to use closer spacing between the first and second wires from the ends of the box than between the other wires.

(d) Binding wires of gages other than those shown in Figures 30, 31, 32, and 33 may be used provided the aggregate cross-sectional area is equal to that required by the figures.

10. Reinforcing wires:

(a) The size of reinforcing wires of flat metal straps around the box (ends and sides, or ends, top, and bottom) when required shall be not less than as indicated in Table 32.

TABLE 32.—*Minimum size of reinforcing wires or flat metal straps*

Weight of contents	One wire	Two wires	One flat metal strap,[1] size
	Gage [2]	*Gage* [2]	*Inch*
150 to 250 pounds	13	----------	3/8 by 0.018
250 to 400 pounds	12	14	1/2 by .018
400 to 570 pounds	11	13	1/2 by .023
570 to 800 pounds	10	12	5/8 by .023

[1] Flat metal straps of other widths and thicknesses but of equivalent cross-sectional area may be substituted for the sizes indicated.
[2] Washburn & Moen gage.

11. Use of heavier material: Nothing herein contained shall be construed as prohibiting the use of boxes constructed of thicker thin boards, additional or heavier wires, heavier cleats, longer staples, or with closer spacing of staples.

VI. METHOD OF INSPECTION AND TEST

1. Visual and manual inspection: The boxes shall be inspected visually and manually for compliance with the specifications, particularly that the lumber is well seasoned and that the construction is that of the style of box stated in the order.
2. Measuring instruments: Suitable measuring instruments, such as a micrometer caliper, a graduated scale or rule, etc., shall be used in determining the dimensions of either the boxes or the component parts including wires, nails, and staples.
3. Moisture content: The moisture content of the wood need not be determined by laboratory methods.

VII. PACKING AND MARKING OF SHIPMENTS

1. (See Section VIII, 3.)

VIII. NOTES

1. Scope of specification: This specification applies to all empty wire-bound boxes purchased by the Government for the domestic shipment of Government property by common carrier.

(a) Definition of the wire-bound box and its parts—

(1) The wire-bound box is a container, the sides, top, and bottom of which are stapled to several steel binding wires, and fastened to a framework of cleats at each end by staples driven astride the end binding wires, the ends being nailed or stapled to the end cleats. The box is closed by looping the wires, or by twisting together or otherwise joining securely the ends of each binding wire, the method used depending upon whether the binding wire is sectional or continuous.

(2) By mat is meant that part of the box consisting of the faces which are attached to the binding wires; a knocked-down wire-bound box exclusive of the end pieces.
(3) By cleats is meant those strips of lumber used to form th framework of the wire-bound box and to which the sides, top, and bottom are stapled.
(4) By battens is meant those reinforcing strips of lumber attached to the end faces of the box.
(5) By liners is meant thin strips of wood fastened inside or outside across the grain of the end.
(6) By reinforcing wires is meant those wires which are in addition to, and usually to be applied at right angles to the regular binding wires, after the box has been packed and closed, their principal purpose being to reinforce the end construction.

2. Exceptions to specifications: This specification applies to most domestic shipments in wire-bound boxes. Exceptional commodities may require less protection, while other commodities, especially dangerous articles, may require better boxes than are specified here. In no case shall the container fall below the specifications prescribed in the Interstate Commerce Commission Regulations for the Transportation of Explosives and Other Dangerous Articles for the particular articles to which those specifications apply. (The Interstate Commerce Commission regulations apply to such articles as explosives, inflammable and corrosive liquids, compressed gases, inflammable solids, oxidizing materials, poisons, etc.)
3. Requirements for packing: Since these boxes are packed, closed, and marked by the shipper, and not by the manufacturer of the box, requirements for these operations are not included in this specification (see railroad, express, and parcel post regulations).
4. Well-seasoned lumber: For box construction, well-seasoned lumber has a moisture content of 12 to 18 per cent of the weight of the wood after oven drying at 212° F. to a constant weight.
5. Heavy cleats:
   (*a*) Reinforcement for the heavy cleats is not covered in these specifications.
   (*b*) Relatively few wire-bound box manufacturers are prepared at present to furnish the heavy cleats. Bids should, therefore, be made to cover alternate construction, heavy cleats, or standard cleats with appropriate reinforcement.

APPENDIX H. WOOD CONSUMED IN THE MANUFACTURE OF BOXES AND CRATES, 1928

TABLE 33.—*Wood consumed in the manufacture of boxes and crates, 1928*[1] *by kinds of wood and forms*

[Quantities in thousand feet, board measure]

SOFTWOODS

Kinds of wood	Lumber	Veneer	Bolts	All forms
Cedar, eastern red	5			5
Cedar, eastern white	333		85	418
Cedar, western	21,039			21,039
Cypress	22,164	25	3,659	25,848
Douglar fir	74,804	197	300	75,301
Firs other than Douglas	46,059		6,936	52,995
Hemlock	321,368		722	322,090
Larch	5,271		64	5,335
Pine, southern yellow	1,150,998	35,970	39,385	1,226,353
Pine, western yellow	1,003,588	1,282	657	1,005,527
Pine, white	708,762	40	8,121	716,923
Redwood	209	1	1,401	210
Spruce	278,666	243		280,310
Total	3,633,266	37,758	61,633	3,732,354

HARDWOODS

Kinds of wood	Lumber	Veneer	Bolts	All forms
Alder	30			30
Apple wood				
Ash	11,863	154	1,837	13,854
Basswood	42,421	1,181	13,799	57,401
Beech	29,237	2,198	13,384	44,819
Birch	86,868	13,857	4,977	105,702
Buckeye	1,462			1,462
Butternut	35			35
Cherry	32		126	158
Chestnut	10,567	64	103	10,734
Cottonwood	110,741	8,284	28,927	147,952
Elm	33,312	2,726	11,976	48,014
Hackberry	21		210	231
Hickory	154	43	750	947
Hornbeam	35			35
Maple	72,268	9,578	12,689	94,535
Oak	66,100	30	2,088	68,218
Red gum	251,603	90,560	78,857	421,020
Sycamore	5,196	593	5,431	11,220
Tupelo	97,488	10,529	12,541	120,558
Willow	4,263		835	5,098
Yellow poplar	88,905	1,939	5,775	96,619
Miscellaneous	89	3	50	142
Total	912,690	141,739	194,355	1,248,784
Foreign woods	92			92
Total	4,546,048	179,497	255,685	4,981,230

[1] This table includes wood used in the manufacture of boxes and crates for sale, and also material for boxes and crates manufactured and used by firms that make other wooden products. It does not include material used for boxes and crates by firms that manufacture products of materials other than wood, except in cases where such firms have separate establishments for making boxes and crates. A small percentage of the quantities included in this table was used for baskets.

In some cases the names of woods given in the table include several species; also, some of the woods are commonly known by various trade names, as follows:

Western yellow pine covers not only this species, often known in the trade as "western white pine," "California white pine," "pondosa pine," and "western soft pine," but also includes lodgepole pine.

White pine includes northern white pine (also called "eastern white pine"), western white pine (often called "Idaho white pine"), sugar pine, and Norway pine.

Cottonwood includes also aspen.

Red gum includes "sap gum," which is the trade name for the sapwood of the red gum tree.

Tupelo (known as "tupelo gum," "cotton gum," and "bay poplar") includes also black gum.

Yellow poplar includes also cucumber and magnolia.

Forest Service: The Bureau of the Census cooperating in the canvass. These data form a part of the Forest Survey of the United States.

TABLE 34.—*Wood consumed in the manufacture of boxes and crates, 1928,*[1] *by States and forms of raw material*

[Quantities in thousand feet, board measure]

State	Lumber			Veneer		
	Softwoods	Hardwoods	Total	Softwoods	Hardwoods	Total
Alabama	16, 826	15, 742	32, 568	1, 063	5, 043	6, 106
Arizona	29, 884		29, 884			
Arkansas	17, 571	35, 220	52, 791		10	10
California	652, 119	3, 746	655, 949	1, 283		1, 283
Colorado	10, 778	2	10, 780		390	390
Connecticut	9, 842	887	10, 729			
Delaware	7, 192	600	7, 792	100	367	467
District of Columbia	9		9			
Florida	39, 422	7, 692	47, 114	18, 827	3, 495	22, 322
Georgia	29, 735	14, 294	44, 029	4, 469	2, 111	6, 580
Idaho	41, 812	30	41, 842			
Illinois	74, 987	67, 457	142, 444	344	10, 815	11, 159
Indiana	48, 591	38, 278	86, 869	132	4, 603	4, 735
Iowa	28, 441	10, 555	38, 996		503	503
Kansas	1, 134	470	1, 604		18	18
Kentucky	12, 467	31, 009	43, 476	2, 325	1, 832	4, 157
Louisiana	23, 187	65, 182	88, 369	1, 500	9, 265	10, 765
Maine	103, 551	122	103, 673		8, 451	8, 451
Maryland	65, 265	22, 834	88, 099			
Massachusetts	201, 344	12, 787	214, 131	152	56	208
Michigan	244, 687	66, 399	311, 086	31	8, 992	9, 023
Minnesota	53. 322	20, 472	73, 794		405	405
Mississippi	10, 717	51, 391	62, 108	1, 000	15, 907	16, 907
Missouri	40, 990	36. 471	77, 461	52	1, 862	1, 914
Montana	5, 345		5, 345			
Nebraska	4, 557	5, 295	9, 852			
New Hampshire	130, 518	1, 107	131, 625		3	3
New Jersey	51, 436	5, 171	56, 615		267	267
New Mexico	27, 300		27, 300			
New York	164, 058	22, 322	186, 380	1, 079	1, 655	2, 734
North Carolina	148, 349	20, 477	168, 826	4, 130	20, 271	24, 401
Ohio	65, 831	54, 748	120, 579	516	4, 719	5, 235
Oklahoma	378	1, 526	1, 904			
Oregon	383, 080		383, 080	45		45
Pennsylvania	104, 674	97, 084	201, 758	34	1. 419	1, 453
Rhode Island	11, 877	65	11, 942	100		100
South Carolina	30, 988	23, 967	54, 955	3	7, 712	7, 715
South Dakota	6, 324		6, 324			
Tennessee	18, 886	17, 852	36, 738	63	3, 949	4, 012
Texas	6, 425	27, 870	34, 295	33	6, 677	6, 710
Utah	1, 740		1, 740			
Vermont	10, 015	1, 986	12, 001		8, 550	8, 550
Virginia	153, 748	31, 182	184, 930	377	11, 274	11, 651
Washington	449, 635	6, 402	456, 037			
West Virginia	1, 816	16, 268	18, 084		14	14
Wisconsin	92, 413	77, 728	170, 141	100	1, 104	1, 204
Total	3, 633, 266	912, 690	4, 546, 048	37, 758	141, 739	179, 497

[1] This table includes wood used in the manufacture of boxes and crates for sale, and also material for boxes and crates manufactured and used by firms who make other wooden products. It does not include material used for boxes and crates by firms that manufacture products of materials other than wood, except in cases where such firms have separate establishments for making boxes and crates. A small percentage of the wood included in this table was used for baskets.

Table 34.—*Wood consumed in the manufacture of boxes and crates, 1928, by States and forms of raw material*—Continued

[Quantities in thousand feet, board measure]

State	Bolts			All forms			Firms reporting (number)
	Softwoods	Hardwoods	Total	Softwoods	Hardwoods	Total	
Alabama	--------	170	170	17, 889	20, 955	38, 844	15
Arizona	--------	--------	--------	29, 884	--------	29, 884	4
Arkansas	300	10, 349	10, 649	17, 871	45, 579	63, 450	24
California	--------	--------	--------	653, 402	3, 746	657, 232	127
Colorado	320	500	820	11, 098	892	11, 990	18
Connecticut	--------	--------	--------	9, 842	887	10, 729	45
Delaware	1, 250	2, 256	3, 506	8, 542	3, 223	11, 765	12
District of Columbia	--------	--------	--------	9	--------	9	1
Florida	14, 285	3, 687	17, 972	72, 534	14, 874	87, 408	24
Georgia	10, 874	6, 349	17, 223	45, 078	22, 754	67, 832	29
Idaho	--------	--------	--------	41, 812	30	41, 842	8
Illinois	2, 400	10, 538	12, 938	77, 731	88, 810	166, 541	305
Indiana	125	9, 661	9, 786	48, 848	52, 542	101, 390	177
Iowa	--------	1, 500	1, 500	28, 441	12, 558	40, 999	46
Kansas	--------	650	650	1, 134	1, 138	2, 272	15
Kentucky	--------	805	805	14, 792	33, 646	48, 438	33
Louisiana	--------	4, 120	4, 120	24, 687	78, 567	103, 254	27
Maine	5, 989	22	6, 011	109, 540	8, 595	118, 135	44
Maryland	250	4, 252	4, 502	65, 515	27, 086	92, 601	53
Massachusetts	676	75	751	202, 172	12, 918	215, 090	162
Michigan	1, 485	7, 762	9, 247	246, 203	83, 153	329, 356	209
Minnesota	6, 000	7, 332	13, 332	59, 322	28, 209	87, 531	84
Mississippi	3, 850	7, 724	11, 574	15, 567	75, 022	90, 589	23
Missouri	--------	7, 658	7, 658	41, 042	45, 991	87, 033	83
Montana	--------	--------	--------	5, 345	--------	5, 345	5
Nebraska	--------	200	200	4, 557	5, 495	10, 052	15
New Hampshire	415	2, 000	2, 415	130, 933	3, 110	134, 043	46
New Jersey	972	1, 642	2, 614	52, 408	7, 080	59, 496	63
New Mexico	--------	--------	--------	27, 300	--------	27, 300	4
New York	88	11, 021	11, 109	165, 225	34, 998	200, 223	382
North Carolina	440	2, 015	2, 455	152, 919	42, 763	195, 682	80
Ohio	--------	6, 637	6, 637	66, 347	66, 104	132, 451	220
Oklahoma	--------	266	266	378	1, 792	2, 170	12
Oregon	327	--------	327	383, 452	--------	383, 452	43
Pennsylvania	43	430	473	104, 751	98, 933	203, 684	238
Rhode Island	--------	--------	--------	11, 977	65	12, 042	13
South Carolina	100	3, 200	3, 300	31, 091	34, 879	65, 970	15
South Dakota	--------	--------	--------	6, 324	--------	6, 324	2
Tennessee	2, 033	16, 833	18, 866	20, 982	38, 634	59, 616	46
Texas	2, 800	22, 039	24, 839	9, 258	56, 586	65, 844	46
Utah	200	--------	200	1, 940	--------	1, 940	4
Vermont	47	132	179	10, 062	10, 668	20, 730	36
Virginia	3, 545	19, 721	23, 266	157, 670	62, 177	219, 847	52
Washington	60	--------	60	449, 695	6, 402	456, 097	82
West Virginia	--------	--------	--------	1, 816	16, 282	18, 098	14
Wisconsin	2, 456	22, 809	25, 265	94, 969	101, 641	196, 610	147
Total	61, 330	194, 355	255, 685	3, 732, 354	1, 298, 784	4, 981, 230	3, 133

Forest Service: The Bureau of the Census cooperating in the canvass. These data form a part of the Forest Survey of the United States.

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A PIPETTE METHOD OF MECHANICAL ANALYSIS OF SOILS BASED ON IMPROVED DISPERSION PROCEDURE

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CONTENTS

INTRODUCTION

In all methods of mechanical soil analysis some separations are based on the well-known fact that the smaller particles in water suspensions fall more slowly than larger ones. In elutriation methods the smaller particles are borne upward by a rising water column while larger particles fall. In the early work of the Bureau of Soils the Osborne (*20*)[2] beaker method was used to make silt and clay separations. Whitney (*5*) apparently was the first to use the centrifuge to increase the settling velocities of soil particles. The centrifuge method was then worked out independently by Hopkins (*12*) and Snyder (*27*). In 1904 the Bureau of Soils published its centrifuge method (*5*), which with modifications (*9*) has been used until recently.

The centrifuge method was much more rapid than the beaker method and gave better dispersion than elutriation methods. In this method the silt and clay were separated from the sands by decantations from a shaking bottle, and the silt was separated from the

[1] The authors desire to express their appreciation to those who have assisted in this work. Thanks are due especially to G. B. Bodman of the University of California for soil samples for analysis; to W. H. Fry for microscopical examination of soil separates; to Hubert Lakin, Mrs. Dorotha M. Darnell, and William Stevens of the soil physics laboratory for assistance in the analytical work; and to C. J. Crawley and J. N. Hall of soils investigations' instrument shop for aid in the design and for the construction of apparatus.

[2] Reference is made by italic numbers in parentheses to Literature cited, p. 21.

clay by centrifuging. With trained men checking their silt and clay separations with a microscope micrometer, the analyses generally were reproducible. Dispersion was obtained by shaking a 5-gm. soil sample with 150 c. c. of distilled water containing 1 c. c. of concentrated ammonia. As many as 40 centrifugings were necessary in some cases to give a complete separation. In such cases rubbing the wet sample with a rubber policeman hastened the operation. Later (*6*) rubber balls with lead centers were put into the shaking bottles to assist in cleaning colloid coatings from sand grains and in breaking colloidal aggregates.

About 1919, when attempts were made to determine quantitatively the amount of colloid in soils, it was found that dispersion was not always so complete as had previously been believed. Davis and Middleton (*8*) then studied a number of methods of dispersing soils preparatory to their separation by the centrifuge method. They concluded that some chemical assistance was necessary for complete dispersion and recommended treatment with 0.1 N HCl for one hour followed by washing in the centrifuge to remove excess acid and exchanged ions. The sample was then shaken seven hours in 0.05 N NaOH.

The introduction of the pipette method developed independently by Robinson in Wales (*23*), Krauss in Germany (*16*), and Jennings, Thomas, and Gardner in the United States (*13*), necessitated a more stable and more complete dispersion than was required in the centrifuge method. A study of dispersion was undertaken by the first commission (soil physics) of the International Society of Soil Science, that resulted in the adoption at the First International Soil Science Congress held in Washington in 1927 of two methods for mechanical soil analysis (*19*). One method, called the practical method, secured dispersion by shaking with ammonia, boiling, and rubbing. The other method, designed to secure complete dispersion, prescribed (1) treatment with hydrogen peroxide to remove organic matter, (2) treatment with 0.2 N HCl followed by washing to remove alkaline earth carbonates and adsorbed bases, and (3) treatment with ammonia or sodium carbonate to secure dispersion. The latter method will be referred to hereafter as the international method. No attempt was made to fix the size classes, but an arbitrary relationship between sedimentation velocity and particle size was established.

These two methods, one intended to give partial and the other complete dispersion, represent two diverse purposes of mechanical analysis. In so-called practical methods such as the first the endeavor is made to avoid removing the coating from soil particles or breaking apart slightly cemented sand grains or aggregates of finer material which would not be resolved in tillage operations or under severe weather conditions in the field. Hilgard (*11, p. 88*) objects to the use of acids to disintegrate compound particles, particularly in calcareous sands. In practical methods it is difficult to determine just when a proper degree of dispersion has been reached. For example, Bouyoucos (*4*), in an effort to secure an analysis of the ultimate natural soil structure, does not give the sample as rigorous treatment as the international practical method proposes.

A mechanical analysis based on complete dispersion does not give so true a picture of field structure and associated physical properties as does the practical method, but it does give information more valuable for most purposes. It gives the amount of coarser material stripped of adhering material, the amount of colloid, and usually the approximate amount of organic matter. Since the colloid is the seat of most soil chemical reactions and governs or strongly influences most of the physical properties, the quantitative determination of the finest soil fraction is the most important single determination in a mechanical analysis. In the case of concretions of irreversible colloidal material having adsorptive properties less than that of dispersed colloid but more than that of solid mineral grains, there is some question as to how far dispersion should be carried.

This bulletin reports an investigation of methods of obtaining dispersion of soil material, with special reference to the effect of acid treatment and the use of alkaline dispersing agents. A method for the removal of organic matter from manganese soils is included. A procedure for mechanical soil analysis, based on the most satisfactory of several methods of soil dispersion investigated, is here outlined. This is the method now used in the Bureau of Chemistry and Soils. This method is designed to secure complete dispersion of soil material below 2 mm. in diameter after organic matter and water-soluble material have been removed. Sieves are used to make all separations except those at 5 μ and 2 μ, where the pipette is used.

DISPERSION

Good dispersion is the key to accurate mechanical analysis. By complete dispersion is meant the removal of colloid coatings on sand and silt grains and the separation of aggregates into single grains or groups smaller than 2 μ equivalent diameter. The problem of dispersion is, (1) to obtain, and (2) to maintain suspensions free from aggregation. The chemical and mechanical aids to dispersion considered are treatment with (1) hydrogen peroxide, (2) hydrochloric acid, (3) water, and (4) dispersing agents [3]; electrodialysis; and shaking.

HYDROGEN PEROXIDE TREATMENT

In the analysis of soils high in organic matter G. W. Robinson (*22*) found that dispersion was aided by the removal of organic matter with hydrogen peroxide. He ascribes this effect to the removal of material which cements soil particles into aggregates strongly enough to resist ordinary dispersion methods. Although it is not necessary to remove organic matter in order to secure dispersion of the mineral portion of the soil (*14*), its presence interferes with the separation of the material into size classes. For this reason all samples for routine analysis in this laboratory are treated with 6 per cent H_2O_2, in accordance with the international method.

When manganese dioxide is present in sufficient quantity it is not possible to remove the organic matter by the usual treatment. Since manganese dioxide is the only form of manganese which catalytically decomposes hydrogen peroxide so rapidly that the organic matter is very slowly attacked, the obvious remedy is to convert it into some other manganese compound. W. O. Robinson (*25*) found that if a small fraction of 1 per cent of manganese dioxide was present it could be destroyed by evaporating the sample with a very small excess of

[3] Ammonium hydroxide, sodium hydroxide, sodium carbonate, and sodium oxalate.

oxalic acid. In this investigation, if manganese dioxide was known to be present or its presence was indicated by the violence of the reaction, acetic acid was added, followed by hydrogen peroxide, the purpose being to convert the manganese dioxide into the manganous form which does not interfere with the decomposition of organic matter by hydrogen peroxide.

The effect of acetic acid treatment was determined on duplicate samples of Wabash silt loam from Nebraska. The samples contained about 3 per cent organic matter and 0.11 per cent manganese, calculated as manganous oxide (MnO). The rate of decomposition of hydrogen peroxide indicated that the manganese is not in the form of manganese dioxide. To 10-gm. samples of this soil were added various amounts of finely precipitated manganese dioxide and acetic acid. The amount of carbon dioxide evolved upon the addition of 20 c. c. or more of 6 per cent hydrogen peroxide is shown in Table 1. The amount of carbon dioxide evolved decreased rapidly with the addition of manganese dioxide. The presence of 0.1 per cent (10 mg.) of manganese dioxide did not interfere with the decomposition of organic matter when 10 mg. of acetic acid was used. Blanks run by treating acetic acid with hydrogen peroxide in the presence of manganese dioxide showed practically no evolution of CO_2 due to oxidation of the acid.

TABLE 1.—*Effect of manganese dioxide and acetic acid on the liberation of carbon dioxide from soil treated with hydrogen peroxide*

Soil	Manganese dioxide added	Acetic acid added	Hydrogen peroxide added	Carbon dioxide evolved
	Mg.	*Mg.*	*C. c.*	*Mg.*
Wabash silt loam (10 gm.)	0	0	20	105.8
Do	10	0	20	55.3
Do	50	0	20	17.5
Do	100	0	20	4.0
Do	0	10	20	112.2
Do	10	10	20	112.7
Do	50	20	20	10.5
Do	50	20	40	74.1
Do	50	20	60	174.2

TABLE 2.—*Organic matter removed by the Robinson method from manganese soil treated with acetic acid*

Soil	Manganese dioxide added	Acetic acid added	Hydrogen peroxide (6 per cent) added	Organic matter removed
	Mg.	*Mg.*	*C. c.*	*Per cent*
Wabash silt loam (10 gm)	100	0	40	0.81
Do	100	100	10	1.38
Do	100	0	60	1.19
Do	100	100	60	1.73
Do	100	0	80	1.18
Do	100	100	80	1.85
Do	0	0	(2)	3.10
Do	10	1 10	(2)	2.95
Do	100	1 100	(2)	2.85
Do	200	1 200	(2)	2.93

1 A slight excess over the equivalent amount of acetic acid was used.
2 An excess of hydrogen peroxide.

When soil is treated with hydrogen peroxide the organic matter either is destroyed with the evolution of carbon dioxide or is brought into solution. Table 1 shows only the amount of organic carbon oxidized to CO_2. Table 2 gives the total organic matter removed by both means when the same soil, containing amounts of manganese dioxide, is treated with different amounts of hydrogen peroxide. The quantity of acetic acid added was a slight excess over the molecular equivalent of the manganese dioxide present. The addition of acetic acid is quite effective when the soil contains 1 per cent of manganese dioxide, 40 c. c. of hydrogen peroxide removing nearly as much organic matter when acid was present as was removed by 80 c. c. of peroxide without acid. In the case of the last four samples hydrogen peroxide was added until decomposition of the organic matter was complete. The sample was then washed and dried and the amount of organic matter determined by loss in weight, according to the method of W. O. Robinson (*25*), who removed 3.03 per cent of organic matter from this soil. The results show that organic matter can be completely removed in the presence of manganese dioxide up to 2 per cent. It is possible that soils containing both manganese dioxide and lime carbonates would not respond so readily to acetic acid and hydrogen peroxide treatment. The amount of peroxide required increases with the amount of manganese dioxide present. The removal of organic matter from the sample containing 2 per cent manganese dioxide required the use of excessive quantities of hydrogen peroxide. The removal of organic matter is not essential to the method described in this bulletin and may well be omitted in the case of soils high in manganese dioxide and low in organic matter.

In some cases hydrogen peroxide decomposes the organic matter slowly and incompletely. In one case, recently noted, hydrogen peroxide attacked the organic matter only slightly. After the addition of 1 or 2 mg. of manganese dioxide the organic matter was quickly attacked and apparently completely decomposed.

ACID TREATMENT

In the pipette method of mechanical analysis it is necessary to prepare soil suspensions in such manner that they may be kept in a sedimentation chamber for several days without coagulation into flocs larger than 2μ equivalent diameter. For this purpose treatment of the soil sample with hydrochloric acid has been found helpful because it dissolves alkaline earth carbonates and removes "exchange bases" which later might cause flocculation of the suspension. There are, however, some objections to the use of acid treatment.

In the international method the soil, after decomposition of organic matter, is treated with enough hydrochloric acid to decompose the carbonates and still leave 250 c. c. of solution of 0.2 N HCl. Such rigorous treatment dissolves sesquioxides of iron and aluminum and some silica, although it may not dissolve all the carbonates. An example of this is given by Bodman (*3*). When a sample of Montezuma clay adobe subsoil from California was boiled with 0.1 N HCl, the amount of acid consumed was equivalent to 9.08 per cent calcium carbonate; but if treated with 0.2 N HCl at room temperature in accordance with the international method, acid equivalent to only 1.27 per cent of calcium carbonate was consumed, and part of this consumption must be ascribed to the solution of 0.81 per cent of sesquioxides and silica. The amount of carbonates in this soil, determined by the official method (*1 p. 22–24*), was 8.28 per cent. The mechanical analysis of this material is given later in Table 5.

Even though carbonates might be removed completely and easily, such removal is undesirable in some soils, such as glacial soils containing large amounts of limestone or dolomite, because it would be likely to change soil textural classifications. Other soils may have relatively permanent grains or crystals of precipitated carbonate whose presence should be expressed in the results of mechanical analysis. An example of this is the Goliad fine sandy loam subsoil from Texas. Ten-gram samples of this material were treated with varying amounts of acid, following the regular peroxide treatment. The washed residues were shaken with 5 c. c. of normal sodium carbonate and analyzed by the pipette method described later. The results are shown in Table 3. An examination of the material by William H. Fry, soil petrographer of this division, showed that the carbonate material, amounting to about 38 per cent, was present largely in the form of small calcite crystals.

TABLE 3.—*Effect of acid treatment on the results of mechanical analysis*[1] *of Goliad fine sandy loam (35 to 48 inches)*

Treatment	Sands 2.0 to 0.05 mm.	Silt 0.05 to 0.005 mm.	Clay <0.005 mm.	Colloid <0.002 mm.	Hydrogen peroxide and solution loss
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*
No acid	36.9	38.6	24.2	18.3	0.2
2 c. c. N $HC_2H_3O_2$	36.6	37.9	24.1	18.1	1.4
10 c. c. N HCl	36.6	34.7	23.3	19.4	5.3
Carbonates removed+10 c. c. N HCl	31.4	9.6	19.9	18.0	39.0
No acid, dispersed with sodium oxalate	37.0	34.3	28.4	21.0	.2

[1] Results in all mechanical analysis tables are on oven-dry basis (105° C.), and silt is reported by difference.

For some special purposes, such as dam construction or other engineering uses, an analysis based on vigorous acid treatment might be preferred for a soil such as the Goliad, although an analysis without acid treatment together with a determination of total carbonates would be preferable. Analyses by both methods are required to furnish a complete description of the soil.

These analyses (Table 3) are presented primarily to show that acid treatment may alter the amount of material in the different size classes enough to change markedly the textural classification. Incidentally they indicate that acid treatment is not essential to good dispersion, a matter which will now be examined more fully.

Since it appears that treatment with 0.2 N HCl is not always effective in removing the carbonates from soil and in some cases presents a distorted picture of the soil, it seemed desirable to ascertain whether complete dispersion can be obtained without its use.

Table 4 gives the results of mechanical analysis of a number of soils with and without acid treatment. All samples (10 gm.) were first treated with hydrogen peroxide. Those given acid treatment were allowed to stand overnight in HCl solution of sufficient strength to leave 150 c. c. of 0.2 N HCl after the carbonate content is removed.

The difference in dry weight of the sample before and after pretreatment is reported as solution loss. This comprises the loss of organic matter, sesquioxides (R_2O_3), silica, lime carbonates, or other dissolved material. All samples were peptized by shaking with 150 c. c. of water containing 10 c. c. of 0.5 N $Na_2C_2O_4$. These samples embrace a wide range of soil types and are representative of soil samples received for analysis.

TABLE 4.—*Effect of acid pretreatment on mechanical analysis of soils*

Sample No.	Soil type and source	Depth	Treatment	$CaCO_3$	Sand 2.0 to 0.05 mm.	Silt 0.05 to 0.005 mm.	Clay $<5\ \mu$	Colloid $<2\ \mu$	Solution loss	R_2O_3 loss
		Inches		*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
425250	Ruston fine sandy loam (Mississippi).	50 to 70	Acid	0	56.2	13.9	29.7	25.6	0.1	0.2
425250	do	do	No acid	0	56.4	14.1	29.3	27.0	.1	.03
304041	Isabella loam (Michigan)	1 to 2	Acid	0	58.0	30.5	6.8	4.2	4.5	.5
304041	do	do	No acid	0	57.0	29.9	8.7	3.8	4.3	.1
2437209	Coxville clay loam (South Carolina).	5 to 15	Acid	0	17.7	26.2	55.1	45.5	1.2	.6
2437209	do	do	No acid	0	17.5	25.2	56.3	48.8	1.0	.05
376337	Paxton very fine sandy loam (Nebraska).	24 to 44	Acid	5.6	52.1	27.9	11.4	9.4	8.6	1.3
376337	do	do	No acid	5.6	55.1	24.5	20.0	16.1	.4	.01
---- --	Houston black clay (Texas).	0 to 12	Acid	[1] 11.7	4.1	25.0	56.3	50.7	14.7	1.7
------	do	do	No acid	[1] 11.7	5.9	28.5	63.8	53.8	1.9	.1
------	Badob (Sudan-Gezira)	do	Acid	5.9	6.3	18.0	69.7	62.4	6.0	2.2
------	do	do	No acid	5.9	8.4	14.7	75.9	64.6	1.0	.04
------	Rendzina (Cejc)	do	Acid	5.1	31.8	26.4	30.2	25.7	11.6	2.5
------	do	do	No acid	5.1	33.0	29.0	34.3	28.8	3.6	.6
------	Podsol (Zdar)	do	Acid	0	25.7	35.4	37.1	30.9	1.6	1.3
-- ---	do	do	No acid	0	25.6	36.4	37.8	30.2	.2	.05

[1] Determination by Robinson and Holmes (*26*).

The last three sets of analyses are from samples submitted for analysis to some 20 laboratories by a committee of the first commission of the International Society of Soil Science. The unpublished results collected by this committee and furnished us by R. O. E. Davis give the amount of organic matter in the badob, rendzina, and podsol as 1 per cent, 4.6 per cent, and 0.4 per cent, respectively. The average (unpublished) result collected by this committee from the reporting laboratories for the percentage 2 μ clay (colloid), when hydrogen peroxide and hydrochloric acid treatment was used, was 60.5 for the badob, 26.7 for the rendzina, and 28.6 for the podsol. Joseph and Snow (*14*), using their method which consists of shaking with sodium carbonate, puddling, and decanting by the beaker method without the use of peroxide or acid, obtained 63.3 per cent, 29 per cent, and 27 per cent for the amount of 2 μ clay in the badob, rendzina, and podsol, respectively. W. O. Robinson (*25*) reports 3.6 per cent organic matter in the Houston black clay, determined by the hydrogen peroxide method, and 4.2 per cent determined by combustion. It is apparent from the results in Table 4 that the organic matter was not all removed by peroxide treatment from either the Houston black clay or the rendzina.

Recently Bodman (*3*) published analyses of five well-selected California soils, using two methods. At request of the writers Doctor Bodman furnished this laboratory with samples of these soils. The results of the analyses, together with those of Bodman, are shown in

Table 5. The Montezuma clay adobe soil has a high content of organic matter, and its subsoil has a high content of lime. The Fresno sandy loam has a high content of sodium carbonate; the Aiken clay loam subsoil has a high percentage of iron; and the last is the difficultly dispersible hardpan horizon of the San Joaquin sandy loam.

TABLE 5.—*Mechanical analyses of soils by comparative methods*

Soil type	Depth	Method [1]	Sand 2 to 0.05 mm.	Silt 0.05 to 0.005 mm.	Clay <0.005 mm.	Colloid [2]
	Inches		*Per cent*	*Per cent*	*Per cent*	*Per cent*
Montezuma clay adobe	0 to 12	A	25.0	32.5	36.9	28.1
Do	do	B	24.0	39.3	31.1	15.0
Do	do	C	23.8	32.8	40.2	34.3
Do	32 to 40	A	30.8	34.1	32.3	26.2
Do	do	B	27.5	43.0	26.7	14.4
Do	do	C	27.3	34.6	37.9	31.7
Fresno sandy loam	0 to 12	A	61.8	29.3	7.5	3.7
Do	do	B	64.2	26.4	7.8	3.7
Do	do	C	62.3	28.8	8.2	5.5
Aiken clay loam	12 to 14	A	6.5	34.8	58.3	45.7
Do	do	B	7.0	35.2	57.3	43.4
Do	do	C	8.2	33.3	58.1	48.6
San Joaquin sandy loam	25 to 30	A	70.7	18.0	10.7	4.9
Do	do	B	58.4	25.5	15.5	6.4
Do	do	C	66.1	15.7	17.9	11.8

[1] Method A, hydrogen peroxide-hydrochloric acid pretreatment, shaken with ammonia. Method B, rubbed with ammonia, shaken with ammonia; separates treated with hydrogen peroxide. Method C, hydrogen-peroxide pretreatment, shaken with sodium oxalate.
[2] Methods A and B, colloid pipetted at 1 μ. Method C, colloid pipetted at 2 μ.

The results given under methods A and B are those published by Bodman, and under method C those obtained in this laboratory. Method A is the international method designed to give complete dispersion. In methods B and C hydrochloric-acid treatment is omitted, hydrogen peroxide being used as the last step in the analysis of the former and the first step in that of the latter. In method B the sample, wet with a dilute ammoniacal solution, is rubbed with a rubber pestle for 10 minutes before being shaken. In methods A and B 5-gm. samples dispersed with ammonia and in method C 10-gm. samples dispersed with sodium oxalate are used.

That the larger amount of colloid obtained by method C is not entirely due to the separation being made at 2 μ instead of 1 μ is shown by the fact that the amount of clay is also greater by this method.

The results in Tables 4 and 5, typical of hundreds of analyses of soils developed from a wide range of materials and under a wide range of climatic conditions, are presented to show that in no case is there any indication that acid treatment is necessary to dispersion. Joseph and Snow (*14*) reach the same conclusion in the case of the heavy alkaline soils of Sudan. In their beaker (or centrifuge) method in which the repeated puddling and decantation of suspensions produces a washing effect, flocculation merely increases the number of decantations required for complete separation into size classes. In the pipette method, however, it is necessary for the material to remain in the sedimentation cylinder without coagulation for at least two or three days. Duplicate pipettings of the same suspension taken a week apart show no evidence of flocculation, even though acid pretreatment was omitted. Since acid treatment appears to serve no essential purpose, and may be objectionable, it is omitted in the method in routine analysis.

WASHING

After the soil sample has been pretreated it is washed to remove soluble organic matter, dissolved lime, replaced ions (especially bivalent and trivalent cations), hydrogen peroxide, and excess acid if hydrochloric or acetic acid is used. Experiments by Wiegner (*29*) indicate that the removal of electrolytes by thorough washing is necessary in order to obtain a high degree of dispersion by any subsequent treatment. Soils from humid regions are low in soluble salts and usually do not require much washing to prevent flocculation in the dispersion cylinder. For soils subject to low rainfall, however, thorough washing is essential to good dispersion.

As washing proceeds the soil, flocculated by acid treatment, gradually deflocculates again, slowing the filtering rate. Occasionally, however, a soil such as the Cecil of Georgia does not deflocculate on washing. For this reason it was chosen for the following test. Eight duplicate 10-gm. samples were given hydrogen peroxide and hydrochloric-acid treatment. The samples were then washed 1, 2, 4, 5, 6, 7, 9, and 15 times, respectively, by the method described later, and the amount of clay was determined by the pipette method. There was no correlation between the number of washings and the percentage of clay, the results agreeing within the limits of experimental error. The Cecil, a soil developed in a humid climate, is low in soluble salts and does not require much washing. The routine treatment is 6 washings of about 125 c. c. each, removing the solution completely each time. The entire operation requires about one day. When acid treatment is omitted only a fraction of 1 per cent of soluble matter is removed by washing, and no chemical analysis of it is made.

DISPERSING AGENTS

The dispersing agents most used in mechanical analysis are ammonia, sodium hydroxide, and sodium carbonate. In the centrifuge method, in which the soil after dispersion is repeatedly washed and the percentage of clay determined by difference, any of the dispersing agents may be used. When ammonia is used in the pipette method, the amount of ammonia held by the dried colloid is somewhat uncertain. The pipetted solutions are alkaline and consequently absorb carbon dioxide from the air, giving an uncertain increase of weight of the aliquot. If sodium oxalate is used as a dispersing agent this difficulty disappears.

Ammonium and sodium hydroxides give good dispersion when calcium and magnesium carbonates have been removed from the soil. This removal requires a thorough acid pretreatment and washing of the sample. If calcium carbonate remains in the soil after pretreatment, sodium carbonate is a better dispersing agent than either sodium or ammonium hydroxide because the carbonate decreases the solubility of the calcium carbonate while the hydroxides may produce large amounts of the flocculating calcium ions. Sodium oxalate is even better as a dispersing agent than sodium carbonate. Unlike the hydroxides, sodium oxalate frees no alkaline earth hydroxides as a result of chemical equilibriums established. Also, the solubility of the oxalates of calcium and magnesium is much lower than that of the corresponding carbonates. The oxalate does not react with carbon dioxide from the air.

Surface layers of three soil types were treated with hydrogen peroxide but no acid, and shaken with the four dispersing agents, equimolecular concentrations $\left(10 \text{ c. c. } \frac{N}{2}\right)$ being used. This is a smaller amount of ammonia than is generally used but is an adequate quantity of the other deflocculents. Table 6 gives the quantities of 5 μ and 2 μ clay obtained by the pipette method. The total lime computed as $CaCO_3$ was less than 2 per cent for the Carrington and Wabash soils and 13.9 per cent for the Houston. The results indicate that ammonium and sodium hydroxides are not suitable deflocculents for soils which have not had acid pretreatment, and that, of the other two, sodium oxalate gives consistently higher results. The activity of the oxalate ion may cause this increased dispersion. Oxalic acid is often used to clean minerals for petrographic examination. Tests are soon to be made upon the efficiency of lithium oxalate as a deflocculent.

TABLE 6.—*Yield of clay obtained with various dispersing agents* [1]

Soil type and source	Percentage of clay obtained from treatment with—							
	Ammonia		Sodium hydroxide		Sodium carbonate		Sodium oxalate	
	5 μ	2 μ	5 μ	2 μ	5 μ	2 μ	5 μ	2 μ
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Wabash silt loam (Nebraska)	30.7	24.1	33.2	28.5	33.1	28.3	34.5	29.6
Houston black clay (Texas)	38.4	26.4	44.5	30.6	61.3	53.5	63.8	53.8
Carrington loam (Iowa)	7.8	6.4	24.9	21.8	23.4	19.9	24.7	22.9

[1] Average of duplicate determinations.

After it was determined that sodium oxalate gave the best dispersion of soils containing calcium carbonate, tests were made on soils containing gypsum, which is much more soluble in water. Table 7 gives the results of comparative analyses of some special samples of gypsum soils unclassified as to soil type. Nos. 28742 and 28743 are from South Dakota, Nos. 28655 and 28668 from Montana, No. 29735 from Hungary, and No. 5218 from Kansas. Analyses are made by the international method, dispersing with sodium carbonate and by our method, described later, in which acid treatment is omitted and sodium oxalate is used as the dispersing agent. With the exception of sample No. 5218, which contains only 1 per cent of gypsum, the routine washing was insufficient to remove all the gypsum from the soils not given acid treatment. The routine amount of sodium oxalate (10 c. c. N/2) was sufficient to remove from solution the calcium ions formed during the three days in which the suspension stood in the sedimentation chamber. There was no indication of flocculation. The amount of clay and colloid obtained was, in each case, greater by method 2 than by method 1. It is likely that in soils containing larger quantities of a soluble calcium salt, such as gypsum, more thorough washing, acid treatment, or electrodialysis may be required for dispersion unless larger quantities of sodium oxalate are used.

TABLE 7.—*Mechanical analysis of soils containing gypsum*

Sample No.	Gypsum[1]	Method	Sand, 2 to 0.05 mm.	Silt, 0.05 to 0.005 mm.	Clay $<5\ \mu$	Colloid $<2\ \mu$	Solution loss
	Per cent		*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
28742	2.52	[2] 1	37.9	14.5	42.9	40.1	4.7
28742	2.52	[3] 2	37.3	16.8	43.8	40.8	2.0
28743	2.28	1	55.1	10.6	26.3	24.9	8.2
28743	2.28	2	56.2	10.9	31.7	26.3	1.3
28655	1.61	1	14.8	21.1	51.2	38.9	12.9
28655	1.61	2	15.5	23.5	60.0	44.3	1.2
28668	5.29	1	31.6	31.0	31.0	27.1	6.5
28668	5.29	2	31.7	30.7	32.8	28.6	4.8
29735	2.82	2	3.3	46.1	48.2	38.4	2.4
5218	1.04	2	3.6	34.0	60.9	52.7	1.6

[1] Computed as $CaSO_4.2H_2O$ from analysis of total SO_3.
[2] Hydrogen peroxide and hydrochloric acid treatment; dispersed with sodium carbonate.
[3] Hydrogen peroxide treatment only; dispersed with sodium oxalate.

Occasionally a sample flocculates in the sedimentation chambers. This may occur with any of the dispersing agents and with or without a mild acid treatment. The difficulty may be due to the presence of some soluble soil material or of an excess or deficiency of dispersing agent. It is impossible to determine accurately from inspection which is the cause. No investigation of the electrokinetic potentials of these suspensions has been made, but a simple remedy has been found which usually restores dispersion. A Pasteur-Chamberland suction filter is placed in the suspension, and the liquid volume is reduced from 1,000 c. c. to some smaller definite volume, say 200 or 250 c. c. Distilled water is then added to make up the original volume. The suspension is thoroughly stirred and allowed to stand. If flocculation again takes place measured amounts of deflocculent are added until the suspension is stable. This procedure leaves some uncertainty as to the weight of dispersing agent to be deducted from the pipetted aliquots. It is assumed that the filtrate removed has the same concentration as the material left in the cylinder.

ELECTRODIALYSIS

Another means of effecting dispersion is electrodialysis. For samples dispersed in this way the Mattson cell (*17*) was used. By this method carbonates and "exchange bases" as well as the chlorides, sulphates, and phosphates can be removed; so that, in addition to giving an excellent pretreatment for dispersion, electrodialysis enables one to determine the amount of "exchange bases" in the soil. The advantage of electrodialysis over hydrochloric acid treatment is that it does not introduce into the soil a foreign ion which must be washed out later. No washing is required after electrodialysis. The method requires considerable extra equipment, extra time, additional transfers of the sample with attendant possibilities of loss, and, where determination of exchangeable bases is not desired, yields no results that can not more easily be obtained by acid treatment.

SHAKING

After the hydrogen peroxide treatment, the sample is washed, dried at 105° C., and weighed. It is this weight which is later made the basis for the determination of the percentage of material in each size class when the results are used for textural classification. The dried sample is transferred to a 250 c. c. nursing bottle, the dispersing agent is added, and the material is shaken overnight. The shaker has a horizontal movement of 10 cm. and a rate of 120 complete oscillations per minute. Joseph and Snow (*14*) find 2 hours' shaking to be sufficient. In the experiments of Davis and Middleton (*8*) the material was shaken 7 hours. Since the samples used in the laboratory were first dried at 105° C. it is possible that longer shaking is required. Although 16 hours is longer shaking than necessary, it is convenient to let the shaker run overnight. The amount of grinding of soil grains is negligible.

SEPARATION INTO SIZE CLASSES

SIZE CLASSES EMPLOYED

Early in the work of the former Bureau of Soils, the soil sample for mechanical analysis was separated into the following seven size classes:

Diameter, mm.	Conventional name
2.0 to 1.0	Fine gravel.
1.0 to 0.5	Coarse sand.
0.5 to 0.25	Medium sand.
0.25 to 0.10	Fine sand.
0.10 to 0.05	Very fine sand.
0.05 to 0.005	Silt.
$<$0.005	Clay.

Analyses based on the percentage by weight of these size classes are used by the bureau for the textural classification of soils (*7*). The bureau's records contain some 50,000 analyses based on these size classes, and for this reason no change has been made in these classes except to report also the amount of material below 2 μ effective diameter. This is called the "colloid" fraction. The 5 μ clay and the 2 μ "colloid" both contain all particles below diameters of 5 μ and 2 μ, respectively. Usually less than 10 per cent of the clay is between 5 μ and 2 μ in effective diameter. Most of the material below 2 μ has a diameter of only a few tenths of a micron or less, so this fraction may be regarded as essentially colloidal in character. In addition to the eight size classes, this laboratory reports the loss by pretreatment of organic matter and soluble material. When acid treatment is omitted the solution loss represents roughly the amount of organic matter. (See Table 4.) Neither the solution loss nor the amount of 2 μ colloid is used in textural classification. They are reported for information only.

The number of sand fractions may be greater than necessary, but these separations are quickly and easily made. The decimal system of grading, with separations made at 2.0, 0.2, 0.02, and 0.002 mm., would not furnish an adequate number of size classes for the extensive system of textural classification of soils used in the United States. Although the coarse clay is silty in character and the larger silt might be classed as very fine sand it now seems desirable to maintain the present size classification. The simplest changes would be to omit the 5 μ separation, place the material between 5 μ and 2 μ in the silt class, and also omit the 1 mm. sand separation, throwing the material between 2 mm. and 0.5 mm. into one class.

METHOD OF SEPARATION

After the sample has been shaken with dispersing agent it is wet sieved through a Tyler 300-mesh phosphor bronze twilled wire-cloth screen, which passes material finer than 50 μ equivalent diameter. All the clay and the finer portion of the silt is washed through the sieve into a 1-liter sedimentation chamber. The silt remaining with the sands is dry sifted through another 300-mesh sieve added to the nest of sand sieves.

The sedimentation chamber contains only fine material with low settling velocities where the accuracy of pipette sampling is greatest. The suspension in the sedimentation chamber is stirred, and an aliquot is quickly taken with a 25 c. c. Lowy automatic pipette. After the suspension has stood 77 minutes (at 20° C.), and again after standing 8 hours, aliquots are taken at a depth of 10 cm., the material in the chamber being stirred thoroughly each time at the beginning of the sedimentation period.

SEDIMENTATION VELOCITY AND PARTICLE SIZE

All decantation or pipette methods of determining size classes depend on the relation of settling velocity to particle size—and this relationship is not accurately known. The relationship most used is Stokes's, formula (*28*) for the fall of a solid sphere in a viscous fluid,

$$V=\frac{2}{9}\,g\frac{(d-d')}{\eta}\,r^2$$

where V is the settling velocity of a sphere of radius r and density d in a medium of density d' and viscosity η, under a gravitational acceleration or centrifugal force, g.

The international method arbitrarily fixed 8 hours as the time for a particle 2 μ in diameter to fall 10 cm. in water at 20° C. This is the value determined experimentally by Atterberg (*2*), although he does not state the temperature. If Stokes's law holds, as it is assumed in determining settling velocities in other sizes, then fixing the relation between settling velocity and particle size is equivalent to fixing the density of the soil particles. Assuming $d'=1$, taking the values of the viscosity of water given in the international critical tables, and the above values for V and r, Stokes's formula gives 2.61 for the density of the soil particle 2 μ in diameter. That this settling velocity may not be very accurate is indicated by the fact that densities of larger particles, computed from Atterberg's settling velocities and Stokes's formula, range from 1.64 to 2.03.

Joseph and Snow (*14*) use a settling velocity of 10 cm. in 7.5 hours, which corresponds to an average particle density of 2.71. Most specific-gravity measurements of clay give values above 2.7. Robinson and Holmes (*26*) have shown that the average chemical composition of soil colloid is quite different from the composition of the sand fraction. The higher specific gravity of the colloid may be due, then, either to difference in composition or to the change in density of water in the micropores and in the surface films of high curvature and large total area, surrounding the particles. For purposes of mechanical analysis it is important to know not only the average density of the soil particle of diameter 2 μ, but also the character of the particle, whether it is a solid mineral grain or an aggregate, or whether it is a gel or has a gel coating. The particles are too small to permit the application of the usual petrographic methods.

There is also some uncertainty as to the validity of Stokes's law for such a large range of particle shapes and sizes. Millikan (*18*) found it necessary to add a correction to Stokes's formula for spheres falling in a gas when the mean free path of the gas molecules exceeded a small fraction of the diameter of the sphere. In applying Stokes's law to the settling of sludges, C. S. Robinson (*21*) used the viscosity and density of the suspension instead of the solution and a coefficient other than 2/9 for the particle shape factor. It is proposed to study the relationship of settling velocity and particle size in the near future. In the meantime it seems best to conform to the relationship used in the international method.

The average density of soil particles at any given size is chiefly a matter of academic interest if size fractions are expressed in terms of settling velocities, as recommended by G. W. Robinson (*24*) rather than in terms of equivalent diameters. But in a method in which five separations are made by sieving and only two by settling velocities, and the results are for the use of field investigators, it seems preferable to hold to the concept of particle size.

Joseph and Snow (*14*) have shown that, for five soils, considerable variation in temperature, time, or depth of pipetting produces a negligible error in the determination of 2μ clay but that a higher relative accuracy is required for larger particles. It has been noticed in this laboratory that the higher the sedimentation velocity the more difficult it is to secure good checks from pipette sampling. One reason is that, after the suspension has been stirred, several minutes are required for the turbulent motion to die down and permit settling to proceed undisturbed.

Formerly when all material smaller than 100 μ was sieved into the sedimentation chamber, a pipette determination was made at 50 μ. The pipette was then fitted with a metal tip, closed at the bottom, and provided with six small equally spaced holes drilled horizontally through the wall of the tip near its lower end. This tip assisted greatly in securing good duplicates, but it was found preferable to make this separation with a finer sieve. The tip was then used in the determinations of clay and colloid in an effort to secure a cross section of the liquid at the desired depth. Observations on particles of lampblack indicated that a pear-shaped volume, with the tip near the bottom of the pear, was removed by this means. The results thus obtained were no more consistent than those obtained with the plain straight glass tip so that the removable tip was abandoned. According to Kohn (*15*), who has worked out the hydrodynamic principles involved, a pipette with any kind of tip, straight or bent, should remove a sphere of liquid whose center is the opening of the pipette tip. It is necessary that the rate of filling the pipette be high in comparison with the settling velocity of the largest particles.

OUTLINE OF METHOD

GENERAL STATEMENT

In view of the foregoing facts the writers desire to present a detailed method of procedure for carrying out the mechanical analysis of soils. This procedure is the one now in use in the Bureau of Chemistry and

Soils. It differs from the international method in certain particulars, viz, the omission of hydrochloric acid treatment, the method of filtering and washing, the drying and weighing of the sample after pretreatment, the use of sodium oxalate as dispersing agent, the use of a finer sieve for wet sieving, and the fact that there is only a single transfer of the sample before separation into size classes. This procedure is more rapid and, it is believed, more accurate than the international method.

PREPARATION AND DISPERSION OF SAMPLE

The sample of soil for analysis is mixed with a large spatula, and is then quartered. The quarter reserved for analysis is rolled with a wooden rolling-pin to break up clods and then is passed through a sieve with 2-mm. round holes. Care is taken in all mixing and quartering to see that the fine material on the paper is properly distributed. Samples are run in sets of eight.

Two samples of each soil are weighed out at the same time, a 10-gm. sample for analysis and a 5-gm. sample for moisture determination. The latter is dried at 105° C. for 16 hours, cooled in a desiccator, and weighed. The 10-gm. sample is put into a 250 c. c. Pyrex electrolytic beaker.

To the 10-gm. sample is added 40 c. c. of 6 per cent hydrogen peroxide, and the beaker is covered with a watch glass. The beaker is frequently shaken in order to bring all the organic matter in contact with the peroxide. When the reaction has quieted down, more peroxide may be added where experience indicates that it is needed, and the beaker is placed on a slow steam bath overnight. Then if all organic matter does not appear to have been removed, more hydrogen peroxide of full strength (about 30 per cent) is added. If manganese dioxide is known to be present or its presence is indicated by decomposition of the hydrogen peroxide without removal of organic matter, then a small quantity of acetic acid is added. About 50 mg. of glacial acetic acid is usually sufficient for a soil containing 0.5 per cent MnO_2. Repeated additions of small amounts of hydrogen peroxide appear to give best results. After decomposition of the organic matter the excess peroxide is boiled off.

If acid treatment is desired the sample is cooled and then treated with 10 c. c. of N HCl, made to a volume of 100 c. c. and allowed to stand overnight. If it is desired to remove all the carbonates, enough acid is added so that the concentration of acid in the beaker, after the carbonates are dissolved, will be 0.1 N. This really involves a prior determination of carbonates. In this laboratory, method B of the Association of Official Agricultural Chemists (*1*) is used for carbonate determination.

The sample with or without acid treatment is now ready for washing. This is done by removing as completely as possible the solution from the sample in the beaker with a short Pasteur-Chamberland suction filter. The lower 12 cm. of the filter is sawed off, fitted with a removable stopper, and used for this purpose. The liquid is then removed from the hollow filter core and replaced with distilled water. By means of a rubber bulb back pressure is applied to the filter in order to remove adhering soil material. The sample is well stirred with 125 c. c. of distilled water and the solution again removed by filtration. Six such washings are usually sufficient. If it is desired to determine the quantity of dissolved oxides of iron and aluminum the washings from each sample are saved separately, made slightly alkaline with ammonia, and boiled. The precipitate is washed on a filter paper, dried, ignited, and weighed.

After cleaning and removing the suction filter, the soil sample is evaporated to dryness on a steam bath and then dried in an electric oven at 105° C. for 16 hours (overnight). Upon cooling in a desiccator the sample, still in the beaker, is quickly weighed on a Chainomatic balance. If this weighing is done rapidly the sample will not take up more than 1 mg. of moisture. The sample is then soaked for a few minutes with about 25 c. c. of water, stirred with a rubber policeman, and transferred to a 250 c. c. nursing bottle. The beaker is again dried and weighed, the difference in weight being the portion of the sample left after organic matter and solution loss. This is the portion of the sample upon which the percentage of size classes is based, when the results are used for textural classification. To the shaking bottle is added 10 c. c. of 0.5 N sodium oxalate, and the volume is made up to 150 c. c. It is shaken overnight on the reciprocating shaker described in Bureau of Soils Bulletin 84 (*9*).

SEPARATION INTO SIZE CLASSES

A sieve fitted with Tyler 300-mesh wire screen cloth is clamped above a 1-liter graduated glass sedimentation cylinder on foot, and the clay and finer silt are decanted from the nursing bottle, through the sieve, into the sedimentation cylinder. After a few pourings the clay is completely removed from the shaking bottle. The entire contents are then transferred to the sieve by means of a stream of distilled water. The cylinder is filled to the 1-liter mark with distilled water and set aside for sedimentation. Economical use of water is necessary in decantation and washing on the sieve, because the total volume of the silt and clay suspension is limited to 1 liter.

The sands and remaining silt may then be washed into a platinum dish and dried, but the preferred procedure is to set the wet sieve in a shallow aluminum dish, place in an oven to dry, and then transfer the dry sand and silt into the platinum dish. While the sands are drying, another sieve is used on the next sample. After drying for two hours at 105° C. the sands are cooled in a desiccator, weighed, separated by a nest of graded sieves into size classes, and the weight of each class determined. The summation method of weighing the silt and sands is used. The first sand is weighed, the second sand is added, the total weight determined, and so on. If the sum of the weights of the fractions is equal to the total weight it is assumed that no error in weighing or recording weights has been made.

The material in the sedimentation cylinder is stirred with a motor-driven propeller, shown in Figure 1, and immediately the pipette is filled, before the coarser silt has had time to settle out. The pipette is emptied into a low-form glass-covered weighing dish, and the washings from the pipette added. The time at which this stirring was made is noted. The time required for a particle 5 μ in diameter to settle 10 cm. is computed from Stokes's formula using a density of 2.61 and the viscosity of pure water for various temperatures (77 minutes at 20° C.). A curve is plotted with temperatures as ordinates and time as abscissae. At the time shown on the graph for the temperature, as read from a thermometer hanging in air near the cylinder, the suspension is again pipetted for clay. This time the pipette, clamped vertically to a support (fig. 1), and with stopcock closed, is carefully lowered by a rack and pinion until the tip is just 10 cm. below the liquid surface, as shown by a pointer moving over a fixed scale. In case pipetting can not be done at the correct time the additional depth required for any delay can easily be computed, time

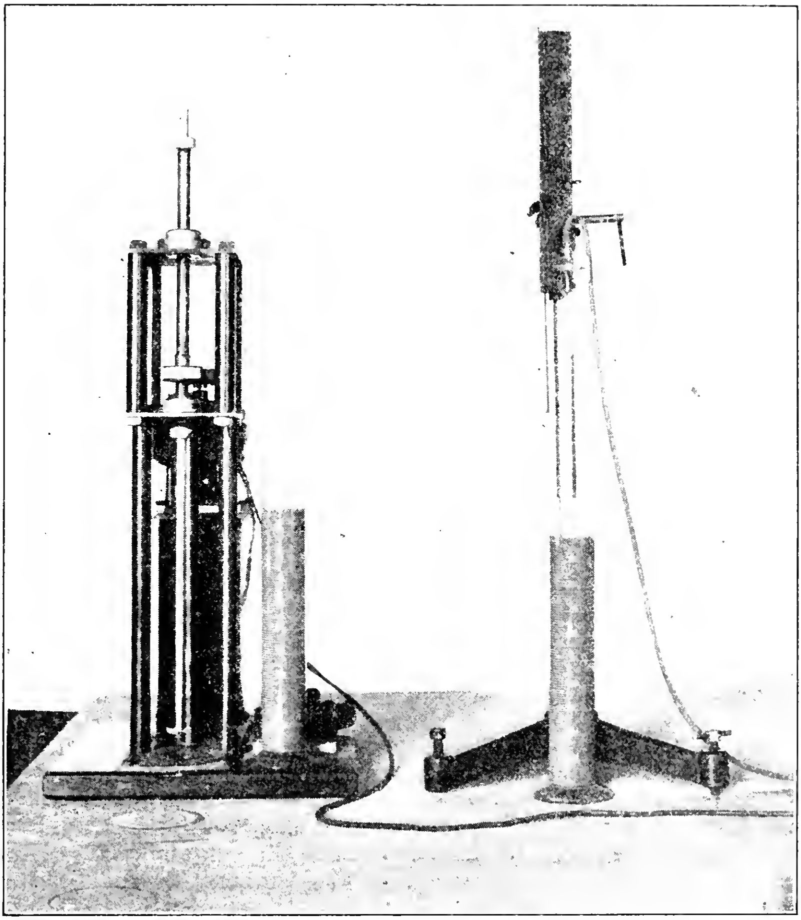

FIGURE 1.—At left, motor and propeller used to stir suspensions; at right, pipette and stand

and depth being directly proportional. This time the pipette is filled with an even suction in about 40 seconds, and the entire contents run into a weighing dish. The pipette is washed two or three times and the washings added to the dish.

Pipetting of the colloid is similar to that of clay except in this case settling time is fixed at six and a half hours, and a graph (fig. 2), computed from Stokes's law, giving the relation of depth to temperature is used.

In ordinary routine suspensions from eight soil samples are placed in a set of sedimentation cylinders, which are covered to prevent evaporation, and are allowed to stand until a convenient time for pipetting. Each suspension is stirred and the first aliquot taken at once. For the second aliquot the suspensions are stirred at 6-minute intervals and samples taken at the end of the required time interval, as read from the time-temperature chart. (Fig. 2.) For the third aliquot the suspensions are stirred early in the day and the samples taken after six and one-half hours at the correct depth as read from the depth-temperature chart. (Fig. 2.) If desired, both charts may be prepared for pipetting at constant time intervals or at constant depth.

It is essential that the pipette be dried each time before filling and that the entire contents be emptied into the weighing dish. The pipette is calibrated for total volume and not for delivery. The aliquots are evaporated to dryness on a steam bath, dried at 105° C. for 16 hours (overnight), cooled in a desiccator, and weighed. Since any

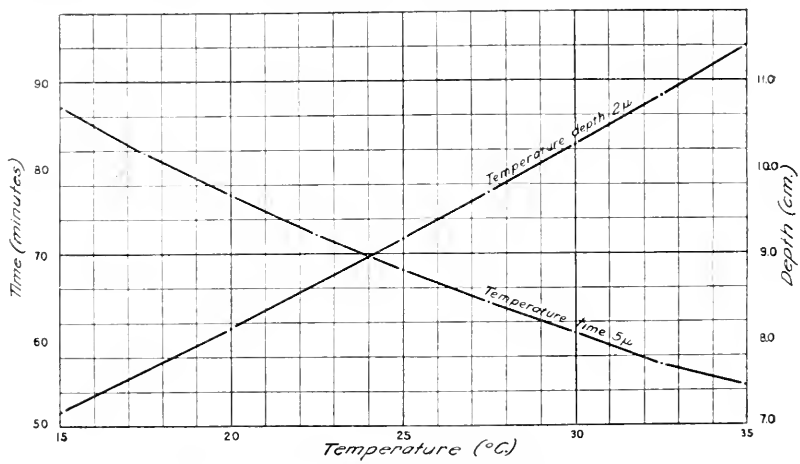

FIGURE 2.—Sedimentation velocity graphs used in the pipetting of clay and colloid

loss of material or error in weighing is magnified nearly fortyfold in the final result, it is necessary to use care in the determination of the pipetted fractions. Weighings are carried to 0.1 mg. and the weight of the dishes is determined each time they are used.

If the room temperature changes rapidly the cylinders are covered with bakelite jackets, but in general room-temperature changes produce only negligible variations. If there is a temperature difference between opposite sides of the cylinder there will be a circulatory movement of the suspension, a condition to be avoided.

Occasionally sets of separates are submitted to William H. Fry of this laboratory for microscopic examination by his methods (*10*). He usually finds the sands practically free from adhering colloid and the silt relatively free from colloidal aggregates.

CALCULATION OF RESULTS

From the moisture determination of the 5-gm. sample, the dry weight of the sample for analysis is computed. After peroxide treatment, and acid treatment if used, followed by washing, the sample is dried and weighed. The difference between the two weights is the hydrogen peroxide-solution loss. The first dry weight, which includes organic matter and solution loss, is taken as the base for calculation of results except when the analysis is to be used for textural classification only. In the latter case the dry weight, after washing, is taken as the base.

From the weight of the first pipetted aliquot, after deducting the weight of the dispersing agent, the dry weight of silt and clay in the sedimentation chamber can be determined directly. It can also be determined by taking the difference between the total weight of the sample before dispersion and the weight of the dry sifted silt and sands. These weights should check, but in every case the weight directly determined by pipetting is slightly greater, varying from a small fraction to as much as 1 per cent or more. The reason for this discrepancy has not yet been found. In routine analyses the dry weight of material in the sedimentation chamber is obtained by difference, but the amount is also determined by pipetting, and if the two results fail to check within 2 per cent the analysis is repeated.

From the weight of the clay and colloid aliquots is deducted the weight of added sodium oxalate and the total amount of material smaller than 5μ and 2μ is computed. No size class between these two limits is established. If the weight of clay is deducted from the total dry weight in the sedimentation cylinder the difference is silt. This is added to the amount of silt sifted from the sands to give total silt.

Below are given the data obtained and the results computed from the analysis of a sample of soil:

Sample No. 561860.
Weight of sample, air-dry, 10 gm.
Moisture (determined on duplicate sample) = 4.89 per cent.
Dry weight of sample at 105° C. = 10.000 − 0.489 = 9.511 gm.
Dry weight of sample (after pretreatment and washing) 9.366 gm.
Solution loss = 9.511 − 9.366 = 0.145 gm. = 1.6 per cent.
Weight of sand (+ some silt) = 2.116 gm.
Silt = 0.046

Sand 2.070 gm.

Size mm.	Weight gm.	Per cent
2.0 —1.0	0.249	2.7
1.0 — .5	.394	4.2
.5 — .25	.312	3.3
.25— .1	.567	6.1
.1 — .05	.557	5.9

Weight of silt + clay aliquot 0.1905 gm.
Weight of clay aliquot 0.1127 gm.
Volume of pipette = 25.12 c. c. = 1/39.8 liter.
Weight of $Na_2C_2O_4$ in 25.12 c. c. = 0.0065 gm.

Weight of clay = (0.1127 − 0.0065) 39.8	4.227	45.1
Weight of silt[4] = 9.356 − (2.070 + 4.227)	3.059	32.7
Total except solution loss	9.365	100.0
Weight of colloid aliquot = 0.0897		
Weight of colloid = (0.0897 − 0.0065) 39.8	3.311	35.4

APPARATUS

A few special pieces of apparatus used in mechanical analysis that have not previously been described are the weighing dishes, pipette, stirrer, sieves, and shaker. The pipette (fig. 1) is a Lowy automatic,

[4] A determination of silt may be made as follows:
Weight of silt aliquot = 0.1905 − 0.1127 = 0.0778 gm.
Weight of silt = 0.0778 × 39.8 + 0.046 = 3.142 gm. = 33.6 per cent.

equipped with a stopcock having an air vent. When the pipette is full a 90° rotation of the stopper will close the stopcock, and an additional 90° rotation will permit delivery. The house vacuum is connected through a fine capillary and a small sulphuric acid trap to the pipette. The capillary permits the desired slow and uniform filling of the pipette, and the sulphuric acid trap keeps moisture from interfering with the air flow through the capillary. The pipette has a delivery volume of 25 c. c. but is calibrated with mercury for total volume.

The stirrer shown in Figure 1 is a motor-driven 4-blade propeller on a sliding shaft which can be clamped at any height to the driving pulley. The variable speed motor is run as fast as possible without whipping air into the suspension. After a suspension has stood for two or three days it is sometimes difficult, with hand stirring, to break up the flakes of silt and clay aggregates which have settled on the bottom of the chamber.

The weighing dishes are of low, flat form in two sizes, one 65 mm. in diameter and 30 mm. high and the other 50 mm. by 30 mm., with correspondingly numbered glass lids ground to fit over the outside of the dish. The small dish is used for the clay and colloid pipetting, and the larger dish is used for the first or silt pipetting, because of the extra washing required to remove the coarser particles from the pipette.

The sieve frames, made from 2½-inch extra heavy brass pipe, are fitted with removable rings to permit the easy change of screens. The two larger sieves have round holes of 1 and 0.5 mm., respectively. The next two screens conform to the Bureau of Standards specifications for 60-mesh and 140-mesh sieves. They have square openings of 0.25 and 0.105 mm., respectively. The finest sieve is 300 mesh and holds particles larger than silt size. The screen wire cloth on the 300-mesh sieve is frequently renewed, as the wire is so fine that it is easily stretched, worn, or broken.

SUMMARY

The method of mechanical soil analysis developed for use in the soil physics laboratory of the Bureau of Chemistry and Soils is described. In pretreatment the organic matter is removed with hydrogen peroxide, but the hydrochloric acid treatment, used in the international method, ordinarily is omitted. A method of removing organic matter in the presence of manganese dioxide is described. Soluble matter is removed by washing and filtering with Pasteur-Chamberland suction filters. The sample is dried and weighed, and this weight is the basis of calculation of percentages of material in each size class, when the results are for use in textural classification. In all operations up to dispersion the sample remains in an extra tall form beaker. The sample is deflocculated by shaking in a dilute sodium oxalate solution. The colloid, clay, and fine silt are separated from the sands by means of a 300-mesh sieve. The clay and colloid are determined by sedimentation, the pipette method being used. The procedure is designed for accurate and rapid analysis.

Investigation of dispersion aids, incidental to this method, discloses the fact that acid treatment introduces undesirable solution losses and is not necessary for dispersion, even in calcareous soils, particularly if sodium oxalate is used as the dispersing agent.

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UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

THE WEARING QUALITY AND OTHER PROPERTIES OF VEGETABLE-TANNED AND OF CHROME-RETANNED SOLE LEATHER [1]

By R. W. FREY, *Chemist*, and I. D. CLARKE, *Associate Chemist, Industrial Farm Products Division, Chemical and Technological Research, Bureau of Chemistry and Soils*

CONTENTS

INTRODUCTION

During recent years the leather industry has been devoting attention to the development of a sole leather by combining two distinct, well-known processes of tanning—namely, chrome tanning and vegetable tanning. The product is referred to as combination tanned, chrome-retanned, or simply as retan leather.

Though the process may vary in many minor respects, it consists essentially in tanning the hides first with chromium salts and then with vegetable materials. The reverse order of tanning has been followed also. The object is to make a leather resembling vegetable-tanned sole leather in such properties as color, firmness, and substance but having the greater durability of chrome-tanned sole leather.[2]

Forest depletion by man and disease is steadily decreasing the supply of vegetable-tanning raw materials. Chrome tanning, moreover, is a much shorter process than vegetable tanning. Because of these conditions and other factors future developments in the leather industry may depend on chrome tanning. With this possibility in mind, the following experiments were made to obtain fundamental data on the wearing quality and other properties of chrome-retanned sole leather as compared to the long-established, well-known vegetable-tanned sole leather.

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[1] It is desired to acknowledge hereby the assistance in this work of L. R. Leinbach, formerly of this division, and the cordial cooperation of the Post Office Department, the Washington City Post Office, and the letter carriers of the District of Columbia.

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HIDES USED IN THE TESTS

An outstanding feature of this study is its strictly comparable nature as the two kinds of leather used were made from alternate right and left halves of the same hides. This fact should be kept in mind throughout the consideration of all the data.

Six steer hides from one lot of shorthorn cattle were used. They were selected at the time of slaughtering and were uniform in size and weight and free from cuts, scores, brands, grubs, and other defects. The hides were salted down in pack on January 27, 1927, and taken up on March 9, 1927.

The uniformity of the weight of these hides is shown by the data given in Table 1 on invoice weights and actual laboratory weights of the green-salted hides. The laboratory weights are higher because of no tare allowances and also because not all the fine salt in which the hides were packed for shipment could be swept off.

TABLE 1.—*Net invoice weight and actual weight of the green-salted hides*

Hide No.	Net invoice weight	Laboratory weight	Hide No.	Net invoice weight	Laboratory weight
	Pounds	*Pounds*		*Pounds*	*Pounds*
1	57.5	61.5	4	58.5	60.5
2	55.5	[1] 65.5	5	57.5	61.0
3	57.5	[2] 60.5	6	57.5	[3] 64.0

[1] Including a manure tare of 7 pounds.
[2] Including a manure tare of 2 pounds.
[3] Including a manure tare of 3 pounds.

DIVIDING, TRIMMING, AND TANNING THE HIDES

Each hide was cut along the median or backbone line into two sides. The two sides of each hide were then superimposed, flesh to flesh. While the sides were held in this position, the head and shank pieces and the edges were closely trimmed off so that the entire outline of one side coincided with that of the other. Holes were punched through the neck and tail ends of each side for identification and for location of points of coincidence. This gave for each hide two sides of practically identical shape and size. The sides were then reweighed.

The trimmed left side of each hide was placed smooth, hair side up, on large sheets of paper, and its outline was traced as carefully as possible for subsequent area measurements.

The left sides of hides 1, 3, and 5 and the right sides of hides 2, 4, and 6 were made into vegetable-tanned sole leather. The remaining sides—that is, the right sides of hides 1, 3, and 5 and the left sides of hides 2, 4, and 6— were made into chrome-retanned sole leather. The products of both tanners selected to make these leathers have a high rating for quality by the trade.

The six sides for vegetable-tanned sole leather were put through the regular tannery process and may be considered as typical, good quality vegetable sole leather. The tanning materials used consisted essentially of chestnut, quebracho, and oak bark.

The six sides for the chrome-retanned sole leather were first put through a regular 1-bath chrome tannage, then neutralized and washed. At this stage they were divided into three pairs of rights and lefts for three degrees of retannage. An effort was made to retan the first pair lightly to show a two-thirds chrome streak in the middle; the second pair to a slightly greater degree, showing a one-third chrome streak; and the third pair to a full retannage, showing no chrome streak. The retanning was done by drumming until practically all the tannin was taken up by the leather. For the vegetable retanning a blend of 3 parts of a 25 per cent tannin chestnut wood extract and 1 part of a 35 per cent tannin sulphited quebracho extract was used. After being retanned and piled for 24 hours, the sides were oiled in a wheel with 1.5 per cent of sulphonated cod oil, set out heavily, tacked, loft dried, and rolled. The grain was not snuffed or buffed, and no waterproofing treatment was applied to the leather.

WEIGHT AND AREA OF UNTANNED SIDES AND OF TANNED SIDES

The actual weights of the trimmed sides before being tanned and after being tanned are given in Table 2. They afford some interesting data on yield, a factor of interest and importance to the tanner. In the table are given constant weights of the sides of finished leather after they had been conditioned for five days at 70° F. and 50 per cent relative humidity.

TABLE 2.—*Actual weight of trimmed sides before tanning and after tanning*

Hide No.	Side	Kind of sole leather	Weight of untanned cured side	Weight of tanned finished side [1]	Ratio of finished weight to cured weight
			Pounds	*Pounds*	*Per cent*
1	Left	Vegetable tanned	24.50	14.50	59
1	Right	Chrome retanned (light) [2]	25.25	8.00	32
2	do	Vegetable tanned	27.50	19.00	69
2	Left	Chrome retanned (light) [2]	26.25	9.75	37
3	do	Vegetable tanned	25.00	17.50	70
3	Right	Chrome retanned (medium) [2]	24.25	9.50	39
4	do	Vegetable tanned	24.00	16.25	68
4	Left	Chrome retanned (medium) [2]	24.00	8.50	35
5	do	Vegetable tanned	22.75	15.75	69
5	Right	Chrome retanned (heavy) [2]	23.50	12.00	51
6	do	Vegetable tanned	26.50	16.50	62
6	Left	Chrome retanned (heavy) [2]	25.00	12.00	48
		Average, vegetable tanned	25.00	16.50	66
		Average, chrome retanned	24.75	10.00	40

[1] Constant weight of finished leather after being conditioned for five days at 70° F. and 50 per cent relative humidity.
[2] Degree of retannage.

According to Table 2, 100 pounds of greensalted, cured, untanned hide yields on the average 66 pounds of vegetable-tanned sole leather but only 35.75 pounds of chrome-retanned sole leather of light to medium retannage and 49.5 pounds of heavy retannage.

The data on the area of the sides before tanning and after tanning are assembled in Table 3. Patterns of the trimmed sides and of the leather made from them were cut from outlines carefully traced on post-card bristol. The patterns were measured in duplicate on a leather-measuring machine of the pinwheel type.

TABLE 3.—*Area of sides before tanning and after tanning*

Hide No.	Side	Kind of sole leather	Area of untanned cured side	Area of tanned side	Ratio of tanned to untanned cured side
			Sq. feet	*Sq. feet*	*Per cent*
1	Left	Vegetable tanned	18. 875	19. 125	101
1	Right	Chrome retanned	18. 875	18. 000	95
2	do	Vegetable tanned	20. 750	21. 125	102
2	Left	Chrome retanned	20. 750	18. 500	89
3	do	Vegetable tanned	19. 250	20. 500	106
3	Right	Chrome retanned	19. 250	18. 375	95
4	do	Vegetable tanned	17. 375	18. 750	108
4	Left	Chrome retanned	17. 375	16. 500	95
5	do	Vegetable tanned	18. 750	(1)	(1)
5	Right	Chrome retanned	18. 750	18. 000	96
6	do	Vegetable tanned	19. 000	19. 500	103
6	Left	Chrome retanned	19. 000	17. 750	93
		Average vegetable tanned	19. 000	19. 800	104
		Average chrome retanned	19. 000	17. 850	94

1 Side 5, vegetable tanned, was stolen from temporary storage before outline tracing was made.

Although the procedure used for determining the area of the sides does not permit highly accurate measurements, the results so obtained are consistent in showing an appreciably smaller area for the chrome-retanned sides. According to these results the area of the cured side is slightly increased when the side is converted into vegetable-tanned sole leather, the average increase being 4 per cent. On the other hand, when made into chrome-retanned sole leather, the area of the cured side decreases, the average decrease being 6 per cent. The averages given in Table 3 show that 19 square feet of cured hide yield 19.8 square feet of vegetable-tanned sole leather and 17.85 square feet of chrome-retanned sole leather. The difference in area between the two sides of hide 2 can be seen in Figure 1. On the left (A) is the chrome-retanned side. Its smaller area as compared with its mate (B) on the right, which is vegetable tanned, is apparent.

From the averages of both Tables 2 and 3, it is calculated that 100 pounds of cured hide has an area of 76 square feet and yields 66 pounds or 79 square feet of vegetable-tanned sole leather; or 49.5 pounds or 71.8 square feet of chrome-retanned sole leather of heavy retannage; or 35.75 pounds or 71 square feet of that of light to medium retannage. In other words, 1 pound of the vegetable-tanned sole leather has an area of 1.2 square feet; 1 pound of the chrome-retanned sole leather of heavy retannage has an area of 1.45 square feet; and 1 pound of the light to medium retanned leather has an area of 2 square feet.

LOCATION OF HALF SOLES AND TEST PIECES IN THE HIDE

The bend portion of each side of leather—that is, the nearly rectangular part extending along the backbone line from the root of the tail to just back of the shoulder and down from this line to the "breaks" or soft spots above the legs—was laid off into half soles and test pieces as shown in Figure 1. The half soles, laid off as alternate rights and lefts, were cut out with a die. After certain measurements of the half soles were made, they were paired, one vegetable-tanned half sole with the exactly corresponding chrome-retanned half sole, as, for example, V–2–11 with C–2–11, V–2–12 with C–2–12, and so on. (Fig. 1.) This not only gave an equal number of right and left half soles for each kind of leather but also permitted rigid control of what is known as the "position" factor,

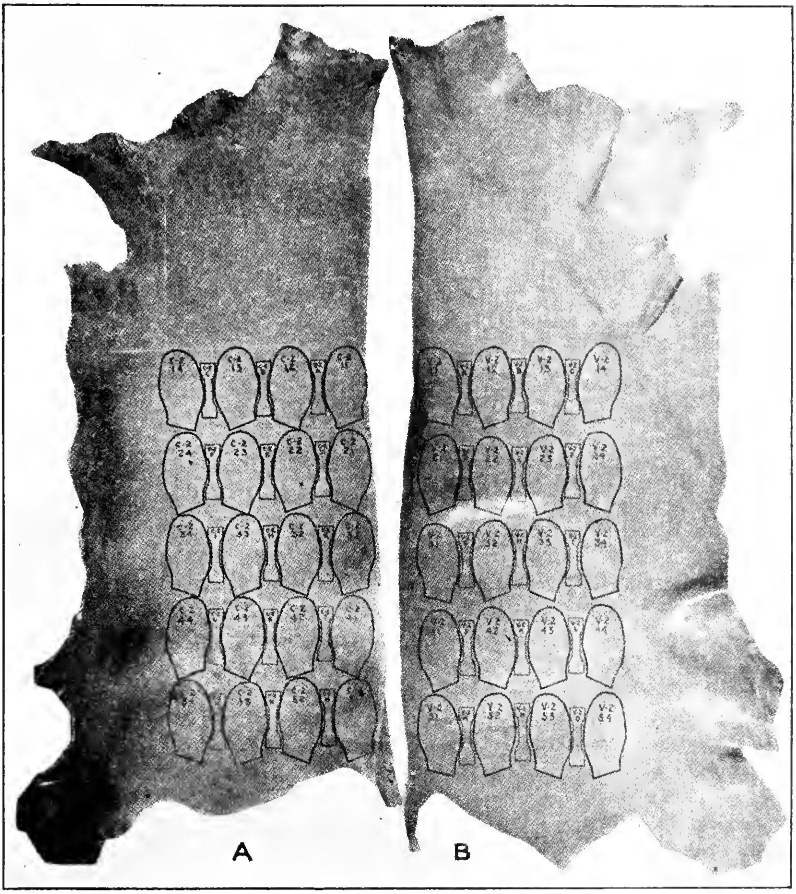

FIGURE 1.—Arrangement of half soles and test pieces: A, Chrome-retanned side of hide 2; B, vegetable-tanned side of hide 2. Half sole C–2–11 was paired with V–2–11, C–2–12 with V–2–12, C–2–13 with V–2–13, and so on

or the influence of the part of the hide from which the sole is cut. Experience and experiments[3] have shown this to be a very important factor in the wearing quality of soles. The half soles, paired as described, were issued for actual wear tests, the details of which will be given further on in the bulletin.

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[3] VEITCH, F. P., and ROGERS, J. S. THE WEAR RESISTANCE OF LEATHER FROM DIFFERENT PARTS OF THE HIDE. Jour. Amer. Leather Chem. Assoc., 13:86–90, 1918. VEITCH F. P., FREY, R. W., and HOLMAN, H. P. LEATHER SHOES: SELECTION AND CARE. U. S. Dept. Agr. Farmers' Bul. 1523, 22 p., illus., 1927.

AVERAGE THICKNESS OF THE HALF SOLES

The thickness of each half sole was measured at five symmetrically located points, and from these measurements the average thickness of the entire bend section of each side was calculated. These figures, together with the figures showing the average thickness of the thickest and thinnest half sole of each bend, are given in Table 4, in thousandths of an inch and in calculated equivalents in irons, one iron being equal to one forty-eighth inch.

TABLE 4.—*Thickness of bend section of tanned sole leather*

Hide No.	Side	Kind of sole leather	Thickness					
			Average	Maximum	Minimum	Average	Maximum	Minimum
			Inch	*Inch*	*Inch*	*Irons*[1]	*Irons*	*Irons*
1	Left	Vegetable tanned	0.156	0.191	0.126	7.49	9.17	6.05
1	Right	Chrome retanned (L[2])	.138	.173	.094	6.63	8.30	4.51
2	do	Vegetable tanned	.171	.205	.138	8.21	9.84	6.62
2	Left	Chrome retanned (L)	.153	.180	.136	7.35	8.64	6.53
3	do	Vegetable tanned	.167	.213	.124	8.02	10.22	5.95
3	Right	Chrome retanned (M[3])	.156	.192	.130	7.48	9.22	6.24
4	do	Vegetable tanned	.168	.200	.133	8.07	9.60	6.38
4	Left	Chrome retanned (M)	.148	.179	.120	7.10	8.59	5.76
6	Right	Vegetable tanned	.178	.212	.144	8.55	10.18	6.91
6	Left	Chrome retanned (H[4])	.184	.210	.144	8.82	10.08	6.91

[1] 1 iron equals 1/48 or 0.02083 inch.
[2] (L) = light tannage.
[3] (M) = medium tannage.
[4] (H) = heavy tannage.

In Table 4 also is indicated the effect of the degree of retannage, the thickness of the heavily retanned side from hide 6 being practically the same as that of the corresponding vegetable-tanned side. The average thickness of the vegetable-tanned bends from the first four sides is 0.165 inch or 7.95 irons; that of the chrome-retanned bends from the same hides is 0.149 inch or 7.14 irons. From these same bends the thickness of the half soles of vegetable-tanned leather ranges from 5.95 to 10.22 irons and of the chrome-retanned leather from 4.51 to 9.22 irons. These data indicate that a long-haired 55 to 60 pound green-salted steer hide will yield from the bend section vegetable-tanned sole leather of an average thickness of practically 8 irons, or chrome-retanned sole leather, of light or medium retannage, of an average thickness of about 7 irons.

AVERAGE BREAKING STRENGTH AND STRETCH OF THE LEATHERS

Test pieces for determination of the breaking strength and stretch of the two leathers were cut out with a die having a test area with parallel sides 2 centimeters wide and 5 centimeters long. The shape of these test pieces and the locations in the hide from which they were cut are shown in Figure 1. Previous to being broken, the test pieces were conditioned for three days at 70° F. and 50 per cent relative humidity, weighed, and measured for thickness at five points equally spaced over the test length.

The test pieces were broken in a motor-driven Schopper machine with jaws set 10 centimeters apart. The rate of separation of the jaws without load was practically 5 centimeters per minute. Stretch was determined by measuring the elongation of the section of the test piece having parallel sides. From the individual results the average breaking load for the bend section of each side was calculated. These figures are given in Table 5 as kilograms per centimeter width, pounds per inch width, kilograms per square centimeter cross section, and pounds per square inch cross section. The stretch is given as the percentage elongation at the breaking load.

TABLE 5.—*Strength and stretch of leather in bend section*

Hide No.	Kind of sole leather	Kilograms per centimeter width	Pounds per inch width	Kilograms per square centimeter	Pounds per square inch	Per cent stretch
1	Vegetable tanned	140	783	341	4,850	22
1	Chrome retanned	91	526	263	3,741	24
2	Vegetable tanned	154	865	343	4,878	20
2	Chrome retanned	106	593	271	3,854	31
3	Vegetable tanned	139	780	317	4,509	19
3	Chrome retanned	91	526	234	3,328	26
4	Vegetable tanned	136	768	313	4,452	17
4	Chrome retanned	81	453	214	3,044	26
6	Vegetable tanned	142	796	306	4,352	19
6	Chrome retanned	94	524	198	2,816	21
	Average, vegetable tanned	142	798	324	4,608	19
	Average, chrome retanned	94	521	236	3,357	26

Considering the common hide basis for these two leathers, the figures in the columns headed "kilograms per centimeter width" and "pounds per inch width" are probably the most interesting as they represent the strength of the leather as is. They show the vegetable-tanned leather to be much stronger than the chrome retanned, the former having a breaking strength of from 45 to 55 kilograms more per centimeter of width. In other words, a strap of the vegetable-tanned leather 1 inch wide would withstand a pull of from 257 pounds to 315 pounds more than a similar strap of the chrome-retanned leather before breaking. When the results are calculated to unit cross section, or pounds required to break a piece of the leather having a cross-section area of 1 square inch, the vegetable-tanned leather is still decidedly stronger than the chrome retanned, showing that the difference in strength of these two leathers is not owing primarily to their difference in thickness.

With increasing degree of retannage the strength of the chrome-retanned leather appears to decrease. The data on this point are too few, however, to justify any conclusions.

Although the vegetable-tanned leather is appreciably stronger than the chrome-retanned leather, its percentage stretch at the breaking load is less. It averages 73 per cent of the stretch of the chrome-retanned leather.

DATA ON INDIVIDUAL HALF SOLES AND TEST PIECES ACCORDING TO POSITION IN THE BEND

For those who may be interested in studying the individual data especially in connection with location in the bend, the average breaking load and stretch of each test piece are assembled in Table 6. These data are listed according to their respective location numbers and letters, as illustrated in Figure 1.

TABLE 6.—*Breaking strength and stretch of test pieces*

Position of side	Hide 1				Hide 2				Hide 3				Hide 4				Hide 6			
	Pounds per inch width of—		Per cent stretch of—		Pounds per inch width of—		Per cent stretch of—		Pounds per inch width of—		Per cent stretch of—		Pounds per inch width of—		Per cent stretch of—		Pounds per inch width of—		Per cent stretch of—	
	V [1]	C [2]	V [1]	C [2]	V [1]	C [2]	V [1]	C [2]	V [1]	C [2]	V [1]	C [2]	V [1]	C [2]	V [1]	C [2]	V [1]	C [2]	V [1]	C [2]
A	661	358	23	29	722	454	20	29	661	409	20	23	812	375	21	22	610	353	17	18
B	627	426	27	29	801	554	22	37	650	476	20	27	846	414	18	27	711	420	23	25
C	745	392	22	28	946	605	21	32	778	487	23	28	655	448	16	24	706	437	17	20
D	818	622	23	23	924	577	17	32	806	515	17	21	784	358	16	19	795	571	17	27
E	924	599	28	28	924	661	24	35	840	582	22	27	739	526	18	35	930	594	21	29
F	762	504	25	25	879	666	20	43	868	571	19	28	823	510	20	29	890	543	23	23
G	851	711	20	23	952	700	21	22	790	610	17	24	818	549	16	22	874	683	20	23
H	935	644	24	21	958	666	26	23	913	554	22	23	756	498	19	24	1036	711	24	23
I	857	571	22	20	935	745	22	24	963	571	21	20	851	493	17	21	840	605	19	18
J	795	465	21	22	806	482	20	26	666	532	17	31	689	420	16	30	689	442	19	24
K	885	543	21	23	851	655	18	30	762	549	17	28	689	532	13	31	778	414	18	21
L	829	599	16	22	862	650	17	38	773	510	18	22	840	510	16	28	795	610	14	24
M	706	459	20	25	711	504	15	31	750	431	19	25	678	381	13	29	834	493	18	29
N	605	409	17	20	767	420	18	31	706	493	21	35	638	358	16	35	644	431	19	29
O	745	588	17	22	941	549	17	29	773	594	17	23	902	426	15	21	801	554	14	20

[1] V=vegetable tanned. [2] C=chrome retanned.

DENSITY OF THE LEATHERS

From the portions of each side remaining after the half soles and test pieces had been cut out, samples were taken for the determination of densities. Samples to represent the kidney location were taken from between half sole locations 32 and 43. (Fig. 1.) For the shoulder location they were cut out of the center of the shoulder, and for the belly section they were taken from the soft flanky portion just below and behind the rear "break." These samples should represent the extremes of texture or fiber structure of a side of leather.

Samples for moisture were taken at the same time, and all samples were conditioned at 50 per cent relative humidity and 70° F. before being weighed and measured.

Volume measurements were made by displacement of kerosene. The procedure followed is a material modification of a method recently described by Porter.[4] Glass tubes of 50 cubic centimeter capacity, 1.5 by 44 centimeters, graduated to 0.2 cubic centimeter, were used. Air-free kerosene was placed in the tube and the volume was read. Vacuum applied for five hours caused no significant difference in the volume of the kerosene. The weighed sample of leather was then introduced, and vacuum was applied intermittently until all the air in the leather was removed, a period of from two to four hours, after which the volume was again read. The increase in volume in the tube gives the volume of the leather minus permeable voids [5] or air spaces. The weight of the leather used divided by this volume was taken as the density, or the weight in air of a unit volume of the leather without voids.

[4] PORTER, R. E. SPECIFIC GRAVITY, PER CENT VOIDS, AND "FILE UP" OF LEATHER. Jour. Amer. Leather Chem. Assoc., 24: 36-42. 1929.

[5] This assumes that displacement in kerosene gives the true volume. The density of materials, such as wood, wool, and cotton, has been found to differ by as much as 0.1 gram per cubic centimeter, depending upon the displacing liquids used.

The leather was then taken from the tube, lightly wiped to remove surface kerosene, and put into a tube containing a known volume of kerosene. The resulting increase in volume gives the volume of the leather plus voids. The weight of the leather divided by this volume was taken as the apparent density, or the weight in air of a unit volume of the leather in its usual condition, including the voids or air spaces.

Correction of densities for moisture was made from data obtained by determining densities of an extra set of composite samples conditioned at 35, 50, and 75 per cent relative humidity, respectively.

In Table 7 densities corrected to a 12 per cent moisture basis are given together with voids, which have been calculated from the difference in volume owing to voids and expressed as percentage of the volume of the leather plus voids. Because of lack of refinement in the procedure used, the density figures probably are accurate only to one or two hundredths and consequently are given only to the second decimal.

TABLE 7.—*Densities and voids of tanned sole leather*

[Corrected to 12 per cent moisture]

Location and hide No.	Apparent density or weight of 1 cubic centimeter of leather and voids of—		Density or weight of 1 cubic centimeter of void-free leather of—		Percentage of voids in—	
	Vegetable tanned	Chrome retanned	Vegetable tanned	Chrome retanned	Vegetable tanned	Chrome retanned
	Grams	*Grams*	*Grams*	*Grams*		
Kidney:						
1	1.04	0.70	1.39	1.39	25	49
2	1.04	.72	1.40	1.39	25	47
3	1.04	.71	1.39	1.40	25	48
4	1.07	.74	1.40	1.40	23	47
6	1.03	.84	1.40	1.41	25	40
Shoulder:						
1	1.08	.66	1.38	1.41	21	52
2	1.06	.73	1.37	1.40	22	47
3	1.05	.75	1.36	1.40	22	46
4	1.09	.71	1.37	1.42	20	49
6	1.01	.79	1.38	1.44	26	44
Belly:						
1	.91	.60	1.37	1.41	34	57
2	.92	.62	1.38	1.40	33	55
3	.93	.64	1.39	1.42	33	54
4	.86	69	1.37	1.41	37	50
6	.93	.65	1.37	1.44	32	54

The values for density of the void-free leather are in surprisingly close agreement, the two types of leather showing no significant differences. The density of the leather from the three locations—kidney, shoulder, and belly—also is practically the same.

The apparent densities, however, and consequently the voids of the products of the two tannages are materially different, the chrome-retanned leather being much lighter and having a much higher percentage of voids. For the kidney area the average apparent density of the vegetable-tanned leather is 1.044 grams per cubic centimeter, whereas that of the chrome-retanned leather ranges from 0.7 to 0.84 gram per cubic centimeter, the latter being the figure for the chrome-retanned leather of the highest degree of retannage. In other words, a sole of the chrome-retanned leather, depending upon the extent of retannage, weighs only from 0.67 to 0.80 as much as a sole of the vegetable-tanned leather of the same area and thickness.

There is also an appreciable difference in apparent density in sections of the same side, at least between the kidney and belly sections, the latter being of a lower apparent density for both tannages.

The data throw no light on relation between wearing quality and density. Although the density of the two types of leather is practically the same, their wear resistance is markedly different. Regarding apparent density, the chrome-retanned leather, which has the greater wear resistance, has a lower apparent density, but for both tannages leather from the belly section has a lower apparent density than that from the kidney section, and yet soles from the belly region are known to have much less wear resistance than those from the kidney section.

The figures for voids are of interest in showing the empty nature of the leather or the volume of air spaces, which in the chrome-retanned leather is roughly one-half the volume of a piece of the leather.

CHEMICAL ANALYSIS OF THE LEATHERS

The composition of the leathers used in these experiments is given in Table 8. The following composite samples were prepared from the broken test pieces from the bend: One to represent the five sides of vegetable-tanned leather; another to represent the two chrome-retanned sides from hides 1 and 2; a third to represent the retanned sides from hides 3 and 4; and a fourth for the heavily retanned side from hide 6. These samples are identified as V, CR 1–2, CR 3–4, and CR 6, respectively.

TABLE 8.—*Chemical composition of the leathers*

Item	Leather samples			
	V	CR 1–2	CR 3–4	CR 6
Moisture .... per cent	7.2	7.7	7.9	7.9
Insoluble ash .... do	0.2	3.6	3.4	2.0
Petroleum ether extract .... do	4.9	2.5	1.7	2.1
Hide substance (N by 5.62) .... do	37.0	62.7	63.2	46.0
Combined tannin .... do	24.1	22.1	20.1	32.2
Water solubles .... do	26.6	1.4	3.7	9.8
Soluble tannin .... do	14.1	0.2	1.4	5.9
Soluble nontannins .... do	12.5	1.2	2.3	3.9
Sugars .... do	4.1	0.1	0.1	0.3
Total ash .... do	1.9	3.8	3.7	2.4
Magnesium sulphate ($MgSO_4 7H_2O$) .... do	4.1	------	------	------
Total chromic oxide (Cr_2O_3) .... do	------	3.0	3.2	2.0
Acidity [1] .... do	0.4	------	------	------
Total sulphates (SO_3)[2] .... do	------	3.2	2.9	1.1
Neutral sulphates (SO_3)[2] .... do	------	1.5	1.4	0.9
PH value [3] .... do	3.4	2.7	2.7	2.7

[1] Procter and Searle method. Methods of Analysis, Amer. Leather Chem. Assn.
[2] Thomas' method. Methods of Analysis, Amer. Leather Chem. Assn.
[3] Kohn and Crede procedure. See the following publication: KOHN, S., and CREDE, E. THE ACIDITY OF VEGETABLE-TANNED LEATHER. Jour. Amer. Leather Chem. Assoc., 18: 189–194. 1923.

As previously mentioned, the analyses show, particularly by comparison of the data on combined tannin and total chromic oxide (Cr_2O_3), that the chrome-retanned sides from hides 1 to 4, inclusive, were practically of the same degree of retannage and that only the side from hide 6 was of a materially higher degree of retannage. They also show that neither the vegetable-tanned nor the chrome-retanned leather had been waterproofed or treated for this purpose with oil or grease preparations.

WEARING QUALITY OF THE LEATHERS

The half soles, cut out and matched as described on pages 4 and 5 with one vegetable-tanned half sole against its corresponding chrome-retanned mate, were issued for actual wear tests to United States mail carriers in the city and suburbs of Washington, D. C., and to messengers in the Department of Agriculture. They were worn from April to December, inclusive. All the half soles were sewed on in the same way by the same shoe repairer without buffing, sanding, or staining. Weekly calendar cards were issued to each wearer, on which records were kept of the hours the shoes were worn each day. These cards were collected, the records checked, and the shoes inspected every week or two. The first half sole of each pair to wear through was replaced by another, and the wearing of the shoes was continued until the other half sole of the test pair was worn through.

The number of hours required by different persons to wear through a pair of test half soles was found, of course, to vary widely, being influenced among other things by the activity of the wearer, the manner of walking, and the nature of the surfaces walked upon. From these individual wear records the average relative wearing quality of the two kinds of leather was calculated for each group of test half soles from each hide. The ratios showing how much longer the chrome-retanned sole leather wore than the vegetable-tanned sole leather are given in Table 9.

TABLE 9.—*Relative wear resistance: Wear of chrome-retanned half soles as compared to wear of vegetable-tanned half soles, the latter in all cases being taken as 1*

Hide No.	Number of test pairs	Wear resistance of chrome-retanned half soles on basis of—			
		Leather as is	Unit thickness of 9 irons	Unit hide substance per unit area	Unit leather substance per unit area
1	14	1.6	1.8	1.6	1.9
2	14	1.8	2.1	1.8	2.1
3	18	1.6	1.8	1.5	1.8
4	18	1.7	1.9	1.7	2.0
6	18	1.3	1.3	1.3	1.2

In 74 out of a total of 82 test pairs the chrome-retanned half sole wore longer than its exactly corresponding vegetable-tanned half sole. In only three cases did the chrome-retanned half sole wear through first. In five instances it wore the same length of time as the vegetable tanned. These 5 were among the 18 test pairs from hide 6, the hide from which the chrome-retanned side of the highest degree of retannage was made, and the only side that in this respect differed markedly from the others, as shown by the chemical analyses.

On the basis of the leather as is, without regard for the difference in thickness between the two types, the chrome-retanned leather from the first four hides wore on the average from 1.6 to 1.8 times, or from 60 to 80 per cent, longer than the vegetable tanned. That from the heaviest retanned side from hide 6 wore only 1.3 times or 30 per cent longer than the vegetable tanned, showing the decided influence of heavy vegetable retanning of chrome leather in reducing the wear resistance.

The chrome-retanned leather of light or medium retannage is thinner than the vegetable-tanned leather made from the same sides. Consequently, when the wear resistance of the leathers from the first four sides is calculated on the basis of the same thickness, 9 irons for example, instead of expressed on the basis of the leather as is, the results show that the chrome-retanned leather has relatively a still greater wear resistance. In the two leathers from hide 6 the relative wear resistance is the same on both bases because the heavy retanned leather was practically of the same original thickness as the vegetable-tanned side.

Relative wearing quality is also expressed in Table 9 on the basis of unit hide substance per unit area or the ratio of the hours required to wear away a piece of the sole 1 centimeter square and thick enough to contain 1 gram of hide substance. The number of hours wear from which these ratios were calculated was obtained by dividing the number of hours actual wear by the grams of hide substance per piece of leather 1 centimeter square.

The value given in each case in Figure 2 is the grams of hide substance in a piece of leather having an area of 1 square centimeter that had been conditioned at 50 per cent relative humidity and 70° F. This value is the product of per cent hide substance, apparent density, and thickness, all determined on the conditioned leather. Hide substance was calculated from nitrogen determined on individual samples cut from the shank end of each half sole. Apparent density was determined on the test pieces distributed between the half soles.

The data in Figure 2 show that a piece of the vegetable-tanned leather contained practically the same quantity of hide substance as a piece of the chrome-retanned leather of equal area made from the same hide and taken from a corresponding position in the side. This quantity may be influenced by a number of factors, such as unequal losses of hide substance before and during the tanning of the sides, changes in the area of the sides, and variations in thickness. Both these leathers were made from the same hides. It is safe, therefore, to assume that the concentration of hide substance originally was essentially the same in both sides of the hide. Considering this and also the data presented in Figure 2 and the previously noted changes in area during the tanning, the sides made into chrome-retanned leather must have lost, either before or during tanning or at both stages, more hide substance than did those made into vegetable-tanned leather, which greater loss was counterbalanced by the relative shrinkage of the chrome-retanned sides, giving again for the two finished leathers about the same quantity of hide substance per unit area for corresponding positions.

The results given in Figure 2 are typical in their relationship of the same data for the leather from the other hides. They show a wide variation in the total quantity of hide substance in a piece of the leather or in a half sole of a given area depending upon the position in the bend. In the vegetable-tanned leather from hide 2 the largest quantity of hide substance in a half sole is 58 per cent greater than the smallest; in the chrome-retanned leather from the same hide this difference is 46 per cent.

The data for all the hides are consistent in showing that the half soles containing the most hide substance are from the kidney and butt region and that those containing the least are from the forward end

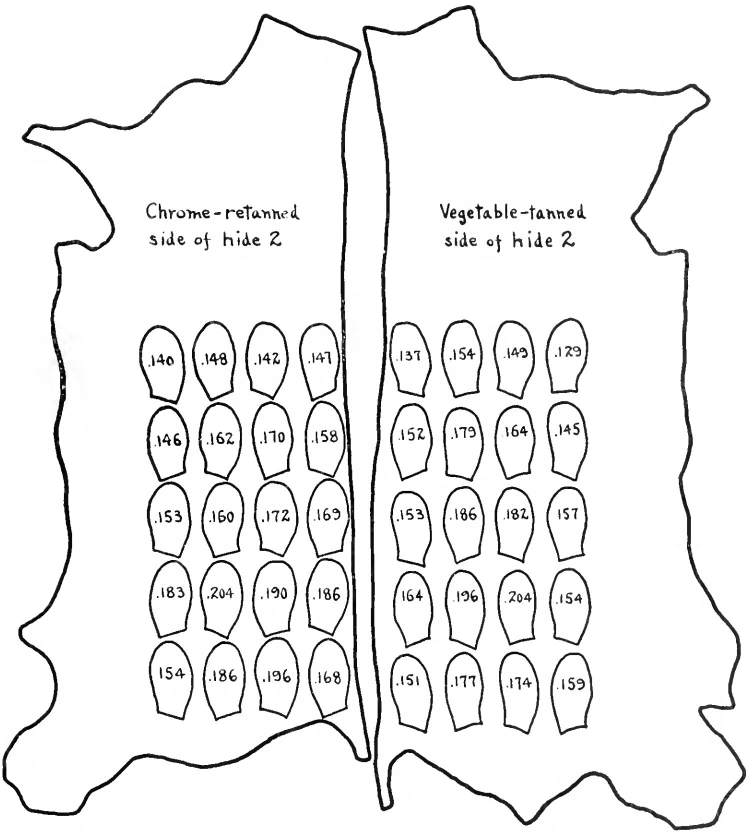

FIGURE 2.—Weight in thousandths of a gram of hide substance per piece of leather 1 centimeter square

of the bend along the shoulder and belly edges. These variations in the quantity of hide substance per half sole from different locations in the bend do not reflect differences in the percentage of hide substance alone, since the quantity is dependent also upon variations in thickness and apparent density.

The data presented in Table 9 on relative wear expressed on the basis of unit hide substance per unit area, considered together with those in Figure 2, show that wearing quality or resistance is not dependent entirely upon the total quantity of hide substance in a sole or piece of leather, since half soles of the two types of leather, from the same relative position in the bend, were shown to have practically the same quantity of hide substance per unit area but materially different wear resistance.

In comparing the wearing quality of sole leathers, especially leathers of different types or of unknown history, it is desirable to express the results for all leathers on a unit or common basis. There are several bases on which relative wear may be expressed, each of which may be objected to on one ground or another. In Table 9 results have been expressed on four different bases, including that of unit leather substance per piece of leather of unit area, or, in other words, on the basis of a piece of leather 1 centimeter square and of such thickness as to contain 1 gram of leather substance, leather substance in the vegetable tannage being taken as hide substance plus combined tannin and in the chrome-retanned leather as the sum of hide substance, chromic oxide, sulphates associated with the chrome, and combined tannin. Such a basis, as a common one for expressing comparative or relative wear of various leathers, is suggested for consideration as possibly least subject to the influence of such factors as loading and filling materials that do not affect the actual wear, and extent and pressure of rolling. For example, two pieces of leather identical in all respects except that one is rolled until it is thinner than the other will wear through in the same time if it is assumed that rolling does not affect the wear, yet if the wear is expressed on the basis of unit thickness the thinner piece of leather will appear to be more wear resistant. A similar condition would be brought about by filling and loading materials that affect the thickness of the leather but not its wear resistance. For practical purposes it is probably best to express wear data on the basis of the leather as is, but for comparative studies and investigational work on fundamental factors that really influence the wear, some common or unit basis to which to refer all results is more desirable.

The rate of wear or wear resistance of shoe-soling materials is not their only property to be considered. Although the data show consistently longer wear for the chrome-retanned leather, especially that of a light retannage, frequent objections were raised against this leather on other grounds. The most important of these were slipperiness and absorption of water during wet weather. Objection was also made, but not so frequently, to the difference between the two leathers in affording protection to the foot when walking. The vegetable-tanned half soles were better in this respect, especially after about one-half the sole was worn away.

An idea of the comparative permeability of the two leathers to water may be gained from the data in Table 10 on water absorption tests. For these tests a piece of leather was cut from the same position in each shoulder along the edge immediately next to the bend. The pieces were conditioned to constant weight at 50 per cent relative humidity and 70° F., and then each one was immersed in 500 cubic centimeters of water for one hour, and flexed ten times by hand at the end of each 15-minute period. After the pieces had soaked for one hour, the excess of water was lightly wiped off with a towel, and each piece was weighed. The pieces were again immersed and left undisturbed for 23 hours, after which they were wiped and weighed as before. The pieces were then allowed to air-dry and were finally reconditioned to constant weight at 50 per cent relative humidity and 70° F. Apparent absorption of water is given as the difference between the weight after soaking one hour and the original conditioned weight, expressed as percentage of the latter. Actual absorption of water is given as the difference between the weight after 24 hours soaking and the final reconditioned weight, stated as percentage of the latter. The results show both a decidedly greater absorption of water by the chrome-retanned leather and the influence of retanning in reducing the absorption.

TABLE 10.—*Comparative absorption of water by tanned leathers*

[Test-piece from shoulder-bend edge]

Hide No.	Apparent absorption in 1 hour by —		Actual absorption in 24 hours by—	
	Vegetable tanned	Chrome retanned	Vegetable tanned	Chrome retanned
	Per cent	*Per cent*	*Per cent*	*Per cent*
1	31	79	56	92
2	33	79	55	90
3	34	85	53	97
4	31	88	59	98
6	37	64	60	69

CONCLUSIONS

The data presented afford a number of interesting comparisons of vegetable-tanned sole leather and chrome-retanned sole leather made from the same hides.

According to these data 100 pounds of long-haired, green-salted, cured hide yields 66 pounds of vegetable-tanned sole leather but only from 32 to 51 pounds of chrome-retanned sole leather, depending upon the degree of retannage.

When converted into vegetable-tanned sole leather the area of the cured side was slightly increased, the average increase being 4 per cent. When made into chrome-retanned sole leather the area was slightly decreased, the average decrease being 6 per cent.

Calculations based upon the averages of the weight and area data show that 1 pound of the vegetable-tanned sole leather has an area of 1.2 square feet; 1 pound of the chrome-retanned sole leather of heavy retannage an area of 1.45 square feet, and 1 pound of the chrome-retanned sole leather of light to medium retannage an area of 2 square feet.

Chrome-retanned sole leather of light or medium retannage is appreciably thinner than vegetable-tanned sole leather made from the same hide. For the hides used, the average thickness of the vegetable-tanned sole leather from the bend section was practically 8 irons, whereas that from the chrome-retanned leather of light or medium retannage was about 7 irons. Heavy retannage increases the thickness to practically the same as that of the vegetable-tanned leather.

As measured over the bend section, the tensile strength of the vegetable-tanned leather is much greater than that of the chrome-retanned, being from 45 to 55 kilograms more per centimeter of width. In spite of this fact, the strength of the chrome-retanned leather appears to decrease with increasing degree of retannage. The data on this point, however, are too few to justify any conclusions.

Although the vegetable-tanned sole leather is appreciably stronger than the chrome-retanned leather, its percentage stretch at the breaking load is less, being on the average but 73 per cent of the stretch of the chrome-retanned leather.

The density, or the weight in air of unit volume of the leather minus permeable voids, is practically the same for the two types of leather. Also, it is the same for the leather from the kidney, shoulder, and belly regions of the sides.

The apparent density, or the weight in air of unit volume of the leather as is, including voids or air spaces, is, however, materially different for the two leathers. For the kidney area the average apparent density of the vegetable-tanned leather is 1.044 grams per cubic centimeter; that of the chrome-retanned ranges from 0.70 to 0.84 gram per cubic centimeter. Leather from different sections of the same side also shows a difference in apparent density, that from the belly section being of a lower apparent density than leather from the kidney section.

The results for percentage voids show a large volume of voids or air in the leather. The percentage is greater in the chrome-retanned leather, being roughly one-half the volume of this leather.

On the average the light to medium retanned chrome sole leather, even though thinner than the vegetable-tanned leather, wore from 1.6 to 1.8 times, or from 60 to 80 per cent longer.

The wear resistance of chrome retanned sole leather decreases with increasing degree of retannage. The chrome-retanned half soles from the bend of heaviest retannage wore but 1.3 times, or 30 per cent, longer than the corresponding vegetable-tanned half soles. Out of a total of 82 test pairs, 74 of the chrome-retanned half soles wore longer. Only 3 of the chrome-retanned half soles wore through in less time than the vegetable-tanned half soles, and but 5 of them in the same length of time as the vegetable-tanned. These 5 were all from the most heavily retanned side.

The data do not show that wearing quality is indicated by tensile strength nor that it is dependent primarily or entirely upon the total quantity of hide substance present per unit area of the leather. Moreover, no relationship is evident between either density or apparent density and wearing quality.

Although the chrome-retanned sole leather wore appreciably longer than the vegetable tanned, it showed several seriously objectionable features. It was quickly penetrable by water, it was slippery in wet weather, and it frequently lacked sufficient solidity to protect the foot against uneven surfaces, especially after about one-half the sole had been worn away. These tendencies were inversely proportional to the degree of retannage and consequently also to their wearing quality. The more heavily the leather was retanned the less readily it became wet, the less it slipped, and the greater was its solidity, but also the less was its relative wearing quality.

A number of different processes are followed in making both vegetable and chrome-retanned sole leather, particularly the latter, including variations in the order and extent of tanning, the time of tanning, and the presence or absence of constituents other than leather substance. Because of these variations and their possible influence on the quality or properties of the resulting products, the data presented here should be considered as applicable only to leather of the types described and not as invariably true of the properties of all vegetable-tanned and chrome-retanned sole leather. It should be borne in mind especially that the chrome-retanned sole leather used was not of the filled or waterproofed type.

From these experiments, from other work, and from practical observations, there can be no doubt of the longer wear of leather entirely or predominately of a chrome tannage. Likewise, there is, as a rule, no question regarding the superiority of vegetable-tanned sole leather in respects other than wear resistance. The development of an entirely satisfactory product combining the good properties of both by a process comparing favorably in speed with that of the chrome-tanning or chrome-retanning processes, is, indeed, worthy of the serious and concerted effort of the industry. Such a process should be attractive particularly to the progressive tanner of vegetable heavy leathers in helping him to solve one of his most serious problems—that is, an extremely slow turnover—to say nothing of the possibility of producing a leather having both a lower production cost and greater serviceability.

ORGANIZATION OF THE UNITED STATES DEPARTMENT OF AGRICULTURE

December 14, 1929

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TECHNICAL BULLETIN No. 168 JANUARY, 1930

THE APPLICATION OF SILVICULTURE IN CONTROLLING THE SPECIFIC GRAVITY OF WOOD

BY

BENSON H. PAUL
Silviculturist, Forest Products Laboratory
Forest Service

UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D. C.

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WASHINGTON, D. C.

THE APPLICATION OF SILVICULTURE IN CONTROLLING THE SPECIFIC GRAVITY OF WOOD

By BENSON H. PAUL

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CONTENTS

Until recently it has been possible to secure easily, whenever needed, wood having the properties desired for a special use. The extent of the progressive exhaustion of our virgin forests, however, now emphasizes our ultimate dependence upon the younger, second-growth forest stands to fill all of our needs for lumber and other wood. When the time of that dependence comes, the difficulty of securing materials well suited for the more exacting wood uses will become infinitely greater, because the supply must then come both from fewer species and from trees of smaller size, that contain a lower relative amount of clear lumber. Learning what growth factors affect the quality of wood the most has consequently become a matter exceedingly important.

This bulletin gives the results of silvicultural studies which show that the specific gravity of the woods studied may be modified by controlling local factors which affect the growth either of forest stands or of individual forest trees, so that it becomes possible, within natural limits, to regulate the specific gravity of wood according to the particular use in view.

HISTORICAL

The investigations upon which this bulletin are based are the first of their kind to be conducted on a comprehensive scale in the United States. In Europe, however, research on silvicultural con-

[1] Maintained at Madison, Wis., by the Forest Service, U. S. Department of Agriculture, in cooperation with the University of Wisconsin.

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trol of wood properties has been in progress for more than half a century.

The investigations of Hartig (*6–10*)[2] undoubtedly hold first place among such efforts abroad. Working with both broad-leaved and coniferous species, he sought to determine the influence of climate and of soil fertility upon the weight of dry wood. He also studied the relations between the rate of growth of trees in diameter and the resulting specific gravity of the wood produced by them.

After carrying on a great many experiments over a period of more than 20 years, he formulated his conclusions into a system which he termed the nourishment theory (Ernährungs Theorie) (*7*). In this theory he held that the specific gravity of wood is dependent upon the relationships of soil fertility, transpiration of water by the tree crown, and assimilation. He asserted that the anatomical structure of wood conforms to the needs of the tree as influenced by external conditions; that the quantity of growth depends upon the total amount of foliage and upon the assimilative energy of the leaves which is affected by the quality of the soil, the sunlight, and the temperature; while the specific gravity of wood is influenced by the proportional quantity of conducting tissue to supporting tissue. The greater the transpiration as compared with the production of wood substance the greater the amount of porous tissue formed and the lighter the wood. Therefore, heavier wood results when the most abundant assimilation possible accompanies a normal transpiration.

The large number of factors included in Hartig's nourishment theory make it difficult to state which factor or factors may be the more important in controlling wood quality. In discussing the weight and structure of wood, Busgen (*3*), probably on account of this uncertainty of factors, gives little credit to the results of research by Hartig (*6, 7, 8, 10*), Sanio (*15*), and Bertog (*1*). He summarizes the "present state of experimental research on the influence of external conditions upon wood structure" by saying: "In this direction but little has been done, although attention has for a long time been directed toward the dependence of anatomical relations upon environment."

The works of other early investigators had a much more restricted scope than the research of Hartig. Cieslar (*4*) found that spruce grown in the optimum of its natural habitat showed higher lignin content than when grown in locations outside its natural limits of distribution. Later (*5*) he investigated the properties of rapidly growing spruce in contrast with slow-growing spruce, basing his study upon a comparison of wood from two stands. A dominant, a codominant, and a suppressed tree were selected from each stand. In both stands he found that the more rapidly growing dominant spruce trees produced wood lower in specific gravity than did the codominant trees, but in one stand the suppressed tree produced wood of high specific gravity while in the other the wood was about the same weight as that of the dominant trees. He found that the higher specific gravity figures corresponded to the wood that contained a greater proportion of summer wood in the annual rings. The results of this work agree with Hartig's ideas that differences occur in the

[2] Reference is made by italic numbers in parentheses to Literature Cited, p. 19.

quality of the wood in the same stand, and yet it can not be said that either the larger or the smaller trees produce the better wood.

Janka (*5*) made additional investigations upon the hardness of the wood in the same trees studied by Cieslar. His work showed that the spruce wood of rapid growth was softer than that of the slower or more normal growth. In investigating the quality of larch wood (*11, p. 51–55*) he could find no relation between the rate of growth and the specific gravity, but he was able to show that the weight depended upon the relative proportion of summer wood in the annual rings.

The work of Hartig, Cieslar, Janka, and other foreign investigators furnishes a background for silvicultural research now under way in this country. While the investigations thus far conducted here do not include all of the possible factors that influence the quality of wood, the results obtained on individual factors are well supported by the experiments of the earlier workers.

FOREST PRODUCTS LABORATORY STUDIES

SIGNIFICANCE OF SPECIFIC GRAVITY AS A BASIS FOR JUDGING WOOD QUALITY

Since 1922 the Forest Products Laboratory has been conducting investigations of the influence of growth conditions upon wood properties. In these investigations, except in a few cases, no mechanical tests of the strength of the wood have been made, since with species in which the relations of specific gravity to strength have been worked out, it is possible to use the specific gravity of wood as a basis for judging the strength when the original position of the specimens in the trees is known. Such specific gravity-strength relations for many of our native species including the species dealt with here have already been established from various tests (*13*), so that the specific gravity of the wood is used as a measure of the mechanical properties of the species in the present investigation.

To illustrate further the significance of the relation of specific gravity of wood to strength, examples, taken from the results of mechanical tests, are given in Table 1 for one of the broad-leaved and for one of the coniferous species included in the present investigation. The tests were made upon small clear pieces of wood tested while in a green condition.

Table 1.—*Relation of specific gravity to strength tests*

Species	Specific gravity (oven-dry), based on weight and volume when green	Kind of test: Static bending, modulus of rupture	Kind of test: Impact bending, height of drop causing complete failure with 50-pound hammer	Kind of test: Compression parallel to the grain, maximum crushing strength	Kind of test: Hardness, load required to imbed a 0.444-inch ball to one-half its diameter: End	Kind of test: Hardness, load required to imbed a 0.444-inch ball to one-half its diameter: Side
		Lbs. per sq. in.	*Inches*	*Lbs. per sq. in.*	*Pounds*	*Pounds*
Pignut hickory (Hicoria glabra)	0.50	8,200	54	3,600	850	780
Do	.62	10,800	70	4,540	1,130	1,200
Loblolly pine (Pinus taeda)	.41	6,870	24	3,050	390	400
Do	.56	8,740	36	4,230	460	500

It may be noted from Table 1 that a difference of 0.12 in specific gravity in pignut hickory was accompanied by a difference of 2,600 pounds per square inch in modulus of rupture, 16 inches difference in height of drop of a 50-pound hammer in the impact-bending test, 940 pounds difference in maximum crushing strength in compression parallel to the grain tests, and 280 pounds difference in end hardness and 420 pounds difference in side hardness tests. Similar differences may also be noted for the loblolly pine.

An attempt was first made to correlate the specific gravity of wood with geographic habitat. This attempt proved ineffectual except for Douglas fir, which grows over a wide area embracing distinct climatic conditions. Preliminary work with Douglas fir from the inland empire[3] showed that the average specific gravity of the wood was intermediate between that of Douglas fir from the Pacific coast and from the higher elevations of the Rocky Mountains. Other species investigated, with attention to specific gravity as related to local growth conditions as well as to general habitat, included white ash, pignut and shagbark hickory, rock elm, sugar maple, and four species of southern pine.

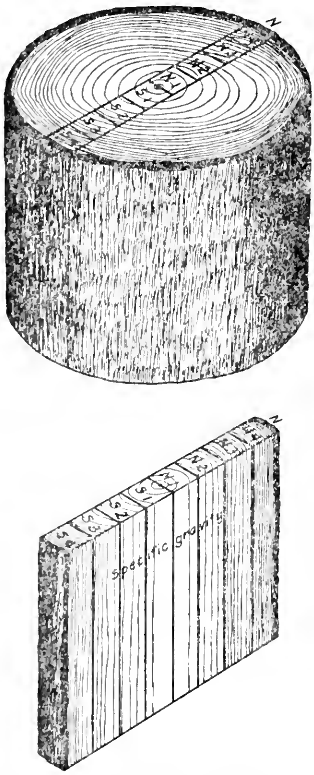


FIGURE 1.—Cutting diagram for specific gravity specimens

METHODS USED IN THE INVESTIGATIONS

The wood collected for the investigations of the several species consisted of cross sections taken from the stems of trees at intervals of about 15 feet. The north-south direction of each section was marked. A description of each tree was made before felling, photographs were taken when possible, and the principal features of the site, soil type, topography, and forest were recorded.[4] Individual trees from which specimens were to be cut were designated by numbers, and each section taken was given its tree number and an identifying letter. The specimens used for specific gravity determinations were taken from flitches which extended in the north-south direction through the center of each tree. (Fig. 1.) The specimens were 6 inches long, about 2½ inches wide, and of varying radial thickness, since they were split off according to groups of annual rings. These groups of rings which occur in such a flitch in pairs, one group on each side of the pith, were matched carefully after

[3] The wooded area lying in northwestern Montana, Idaho north of the Salmon River, Washington east of the Cascade Mountains, and the northeastern tip of Oregon.

[4] The detailed silvical descriptions of the forest stands investigated, as well as the detailed results of the specific gravity determinations, are contained in unpublished reports on file at the Forest Products Laboratory, entitled "Influence of Growth Conditions on Wood Properties." Project 259

splitting the specimens off the individual flitches, and the first grouping of rings selected in a tree, as far as possible, was carried through all the sections taken from that tree; the result gave specimens representative of definite periods of growth, from different heights in the tree. The place of each specimen in the cross section was indicated by number, making it possible at any future time to locate accurately the original position of any individual test specimen.

The radial thickness of each specimen, the number of annual rings included, and the years of formation were recorded in full detail. In addition a carbon imprint of the annual growth rings of each cross section was made. The specimens were allowed to air dry for a period of several weeks and were then brought to constant weight by drying in an electric oven at a temperature of 100° C. Specific gravity determinations were then made upon the specimens by the immersion method.

INVESTIGATIONS OF BROAD-LEAVED SPECIES

WHITE ASH

The first of the broad-leaved species selected for investigation was white ash (*Fraxinus americana*).

In beginning this investigation it was considered advisable to determine, if possible, whether any noteworthy differences in the properties of the wood of this species could be found associated with the geographical location of the stand or with the characteristics of the site. Following the practice of foreign investigators and guided by the results of tests in this country (*12*, *13*) the specific gravity of the oven-dry wood was used as an index of its strength properties.

The first collection of white ash for the investigation was made in the fall of 1922 from regions representing widely different conditions of topography and soil, ranging from the high slopes of the southern Appalachians to the bottom lands along the Mississippi River. Specimens were collected from two places in western North Carolina, from two places in western Tennessee, and from two places in northern Arkansas. Five or more trees were cut in each place.

Average specific gravity values for white ash from these different locations failed to show any striking differences. The only feature that could be attributed directly to the influence of locality was found in the wood from the lower portions of the trees which were cut from the overflow bottom lands along the Mississippi River. This wood was lower in specific gravity than wood from cross sections in the same trees 16 or more feet higher up, in contrast to the wood from all of the other places where the wood at the base of the white ash trees was heavier than that higher up in the trees.

Individual variations characterized the trees from nearly all locations. These variations were not only in the specific gravity of the wood among the trees in the same place but were also within the stems of the individual trees. The wood grown at different periods in the life of a tree sometimes exhibited widely different characteristics.

Specific gravity determinations for the wood produced at different stages of growth were obtained by separating the annual rings into groups including 10, 20, or more rings, representing the various periods of growth, and by splitting out specimens in such a way that the faster and the slower periods of growth would be contained in different specimens.

A general application of the specific gravity results, however, did not indicate any direct relation between the specific gravity of the wood and the width of the annual rings, but when individual specimens exhibiting low specific gravity were considered with respect to the whole life of the tree from which they were cut, they revealed a retardation of diameter growth in the tree. This suggested a relation between specific gravity and some factor that would retard the rate of growth in diameter of the trees. This retardation in growth was believed to be due to a lack of growing space, and, since a dense forest stand is usually associated with slow tree growth, it was considered advisable to determine whether crowding of the trees would influence the specific gravity of the wood and whether any beneficial effects would result from thinnings.

Plots previously established for silvical studies were sought for this investigation but a thinned plot of white ash was not found. The necessary combinations of growth conditions, therefore, were looked for in natural stands. Three suitable wood lots from soils of about equal quality as judged by the height and age of the trees were found in northeastern Ohio. Two of them consisted of even-aged crowded stands in which the trees had reached a stage of keen growth competition. In the third wood lot a heavy thinning had been made about 30 years previous to this investigation. In both of the crowded wood lots the rate of growth in diameter near the circumference of the trees was very slow and was accompanied by the production of wood of low specific gravity. In one of the crowded wood lots the average reduction from the specific gravity of the wood produced at a time when the tree had more growing space was 18 per cent and in the other crowded wood lot it was 11 per cent. In the thinned wood lot the average change in specific gravity since the thinning was only 1 per cent and during the same time the rate of growth of the trees in diameter had greatly increased.

Table 2 gives the results for the specific gravity determinations of white ash trees in the three wood lots.

TABLE 2.—*Comparison of rate of growth and average specific gravity of white ash for different periods of growth in unthinned and in thinned stands*

No.	Description of stand: Kind	Average age	Average height	Average diameter (breast high)	Number of trees	Period of growth	Number of annual rings per inch	Specific gravity	Period of growth	Number of annual rings per inch	Specific gravity	Change in specific gravity
		Years	*Ft.*	*In.*								*P. ct.*
1	Unthinned	60	88	13	5	Before crowding (first 30–35 years).	8.4	0.695	After crowding (last 15 years).	21.3	0.571	−17.9
2	do	50	81	12	5	do	8.5	.674	do	14.9	.599	−11.1
3	Thinned	65	85	15	5	Before thinning (first 35–40 years).	11.0	.661	After thinning (last 30 years).	8.3	.654	−1.0

The study of white ash emphasized the belief that the width of the annual rings or growth layers is not an index of the quality of the wood of this species unless considered with respect to the life history of the individual trees. The following deductions were drawn from the results of the specific gravity determinations:

During the early life of the white ash trees studied, the rate of growth did not seem to influence the specific gravity, since wood of high specific gravity was formed whether the growth was rapid or slow.

The white ash trees that maintained a nearly uniform rate of growth in diameter did not show any great differences in the specific gravity of the wood produced in different periods of their growth.

A retardation of the growth of the white ash trees studied, as exhibited by the formation of narrower annual rings, produced wood of low specific gravity.

An increase in the rate of growth of the white ash trees investigated, following a period of suppressed growth, produced wood of high specific gravity. (Pl. 1.)

When all growth conditions were favorable except space, thinnings in a dense stand of white ash apparently not only assisted in a continuation of the normal tree growth but also assisted in maintaining the wood uniformly high in specific gravity. Thus, wood having the most uniform mechanical properties and the greatest freedom from defects may be produced in white ash trees which are closely stocked in the stand during the early years of its formation, with subsequent thinnings of such degree that the rate of diameter growth of the trees is maintained or increased.

PIGNUT HICKORY AND SHAGBARK HICKORY

To check the results of the investigation of white ash, a corresponding study was undertaken during the spring of 1923 upon hickory, a similar wood. Material for the investigation was collected from two places in the mountain forests of western North Carolina, from three places in the foothills of the Cumberland Mountains in Kentucky, from the north and the south slopes of Mount Logan in southern Ohio, and from two wood lots in southern Indiana. At least five trees were cut in each situation.

Two species of hickory were included in the investigation, pignut (*Hicoria glabra*) and shagbark (*H. ovata*). The specific gravity results conformed very closely to those obtained in the white ash. A sustained or an accelerated rate of diameter growth produced wood of uniform specific gravity and a retardation of the growth rate by crowding or by the deterioration of the site produced wood of nonuniform and lower specific gravity. The effect of unfavorable soil conditions in producing wood of lower specific gravity was revealed in a comparison of the wood of shagbark hickory trees from the north and the south slopes of Mount Logan. The trees from the southerly slope of this mountain were stunted in height growth, were of very poor form, and exhibited a slow rate of growth in diameter during recent years. Slow growth was not the result of crowding as the individual trees had plenty of growing space, but the very poor condition of the site was attributed in large measure to frequent forest fires during recent years, which had on such a southern slope no doubt lessened the moisture-holding capacity as well as the fertility of the soil. The hickory trees on the north side of the same mountain, however, were enjoying very favorable forest conditions although the stand was becoming slightly crowded. The specific gravity results for trees from these two sites appear in Table 3.

Table 3.—*Comparison of rate of growth and corresponding average specific gravity for different growth periods in shagbark hickory from the north and from the south slopes of Mount Logan, Ross County, Ohio*

Situation	Trees	Average age	Total height	Initial growth period		Final growth period	
				Annual rings per inch	Specific gravity	Annual rings per inch	Specific gravity
	Number	*Years*	*Feet*	*Number*		*Number*	
North slope	6	90	80	12.5	0.833	19.4	0.792
South slope	5	70	45	15.8	.803	25.4	.726

The results of the investigation of the pignut and the shagbark hickories (pl. 2) corroborated the conclusions in the study of the specific gravity of white ash (p. 7) and were likewise in agreement with the results of tests of several species of commercial hickory (*2*).

ROCK ELM

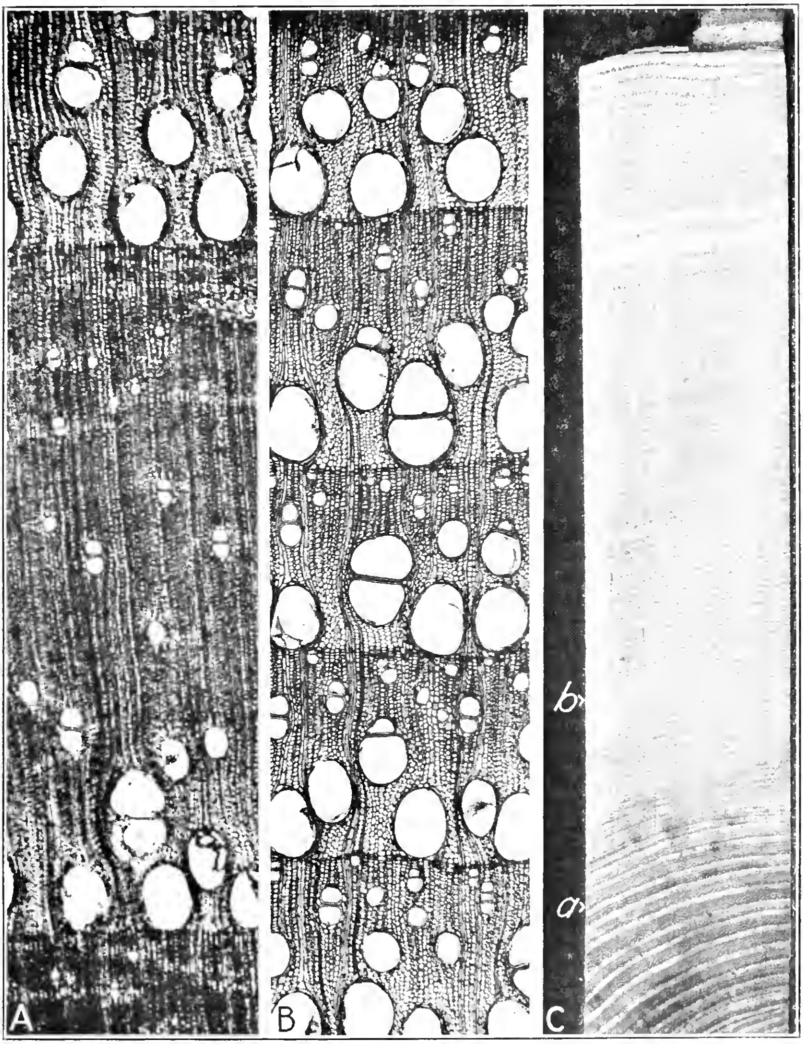
Rock elm (*Ulmus racemosa*) was chosen for further investigation because, being less conspicuously ring porous than ash and hickory, it is intermediate in structure between the typical ring-porous and the diffuse-porous woods. The material for this study was collected in southern Michigan in the fall of 1924. Specimens were taken from only two wood lots, but the results obtained conformed so closely to those for the white ash and the two species of hickory in regard to the relation between growing space and specific gravity that further study of this species was deemed unnecessary. The wood from the rock elm trees in one wood lot showed the effects of a long period of suppression which had been subsequently relieved by a thinning. In the other wood lot the conditions of growth had continued much more favorable.

The effect of the suppression of growth and of the release from crowding upon the specific gravity of rock elm is given in Table 4.

Table 4.—*Average specific gravity for successive growth periods in rock elm trees*

Wood lot No.	Trees	Average age	Initial growth period		Intermediate period of growth		Final period of accelerated growth	
			Annual rings per inch	Specific gravity	Annual rings per inch	Specific gravity	Annual rings per inch	Specific gravity
	Number	*Years*	*Number*		*Number*		*Number*	
1	5	240	28.7	0.712	34.1	0.624	20.7	0.660
2	5	235	31.8	.708	25.3	.706	15.5	.716

The table shows that the first group of rock elm trees produced heavy wood for a considerable period of time, followed by the production of wood of lower specific gravity during a subsequent period

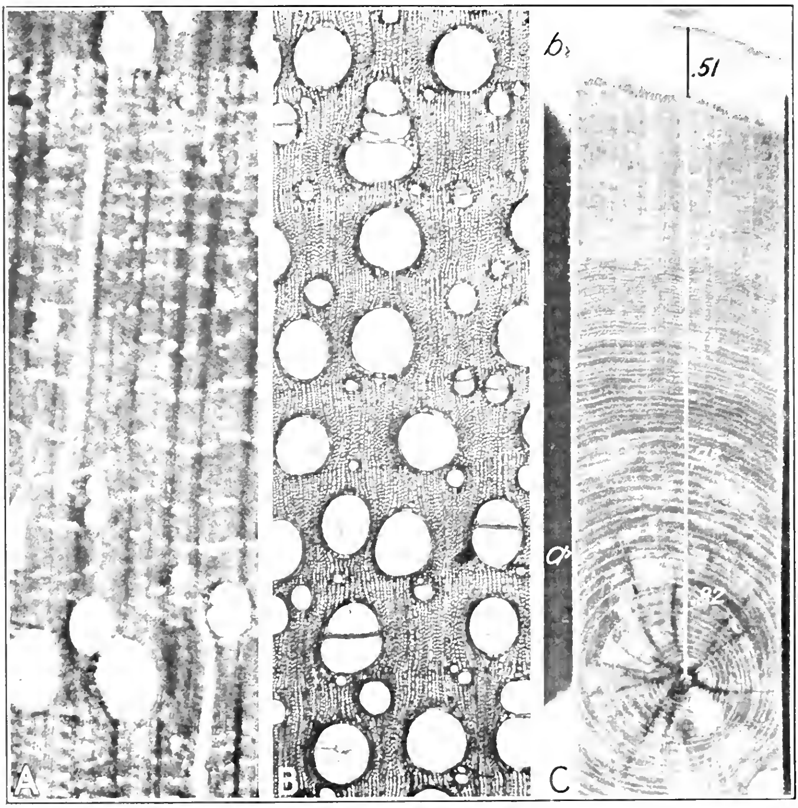


M2671, M2672; M8418F

COMPARISON OF WHITE ASH, SHOWING CHANGES IN RATE-OF-DIAMETER GROWTH AND STRUCTURE OF ANNUAL RINGS

A and B.—The structure of wide and narrow annual rings at points *a* and *b* in C. The specific gravity of the wood in A is 0.65; B is only 0.48.

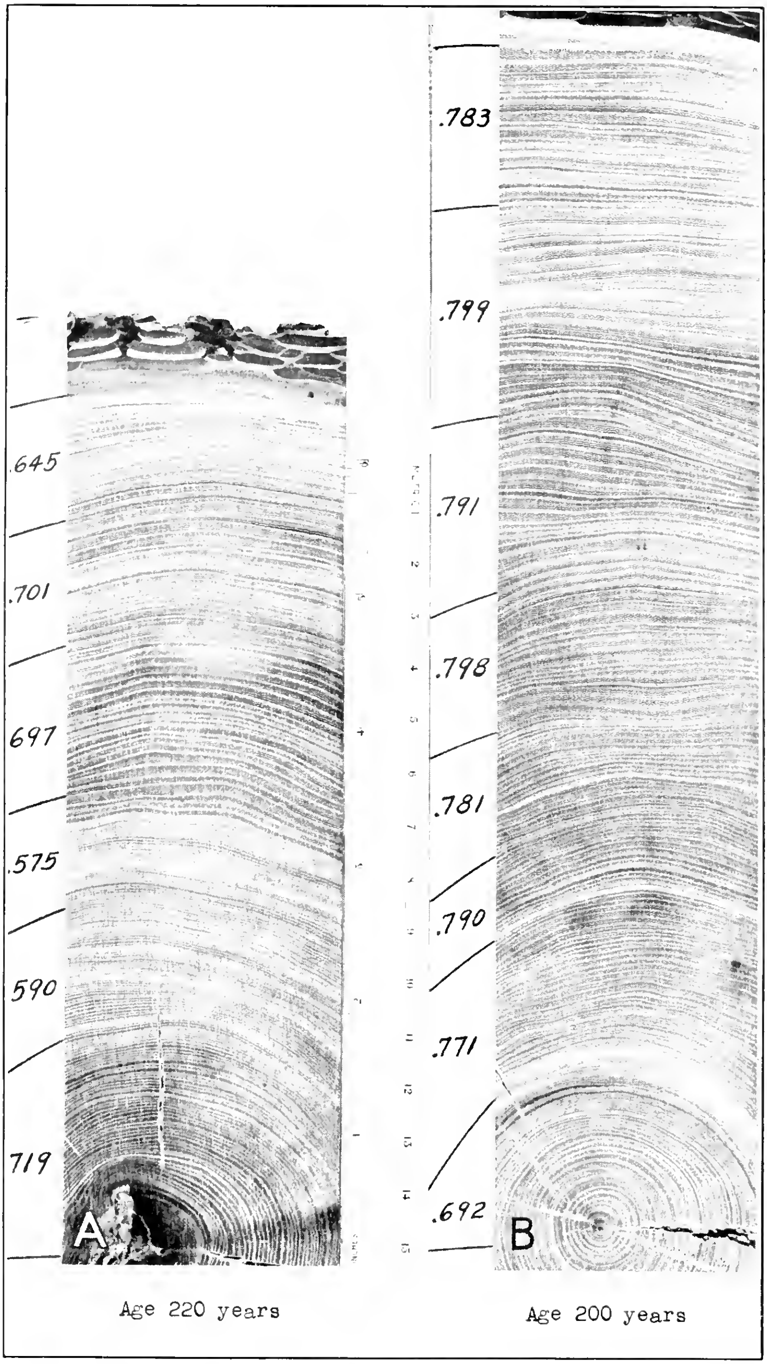
C.—Cross section of white ash. The wood near the center of the tree is of rapid growth and high specific gravity. Wood of slow growth and low specific gravity follows, caused by a long period of unfavorable growth conditions. A change to more favorable conditions is shown by renewed growth and wood of high specific gravity.



M2673; M2674; M3164F

COMPARISON OF PIGNUT HICKORY, SHOWING CHANGES IN RATE-OF-DIAMETER GROWTH, SPECIFIC GRAVITY, AND STRUCTURE OF ANNUAL RINGS

A and B.—The structure of wide and narrow annual rings at points *a* and *b* in C. A has a specific gravity of 0.82, while that of B is only 0.51.
C.—Cross section showing the gradual slowing down of the growth and decrease in specific gravity of the wood caused by lack of room for crown development.

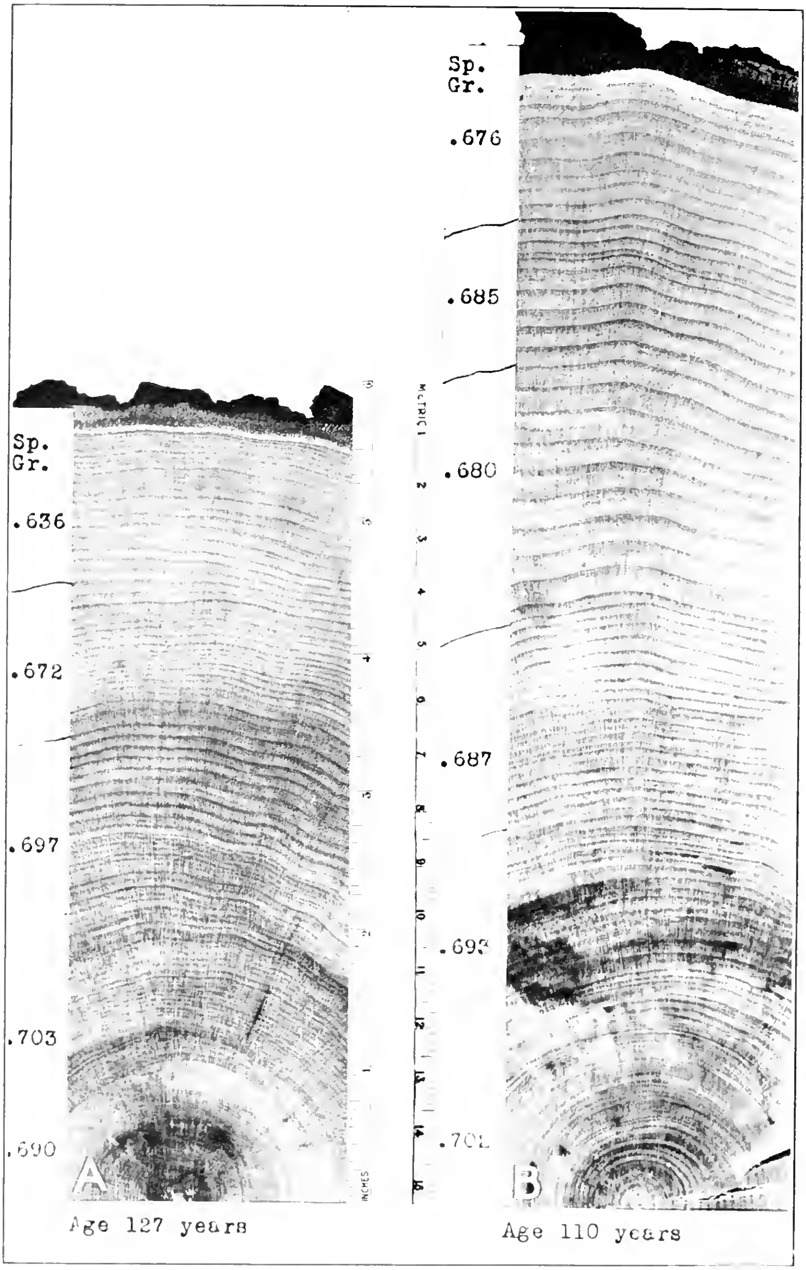


M1740F

COMPARISON OF GROWTH AND OF SPECIFIC GRAVITY IN CROSS SECTIONS OF ROCK ELM

A.—Experienced a long period of crowding, which decreased the specific gravity of the wood, and was followed by a rapid growth period as a result of thinning.

B.—Maintained a dominant position in the stand throughout its life and at 200 years of age was growing rapidly and producing wood of high specific gravity.

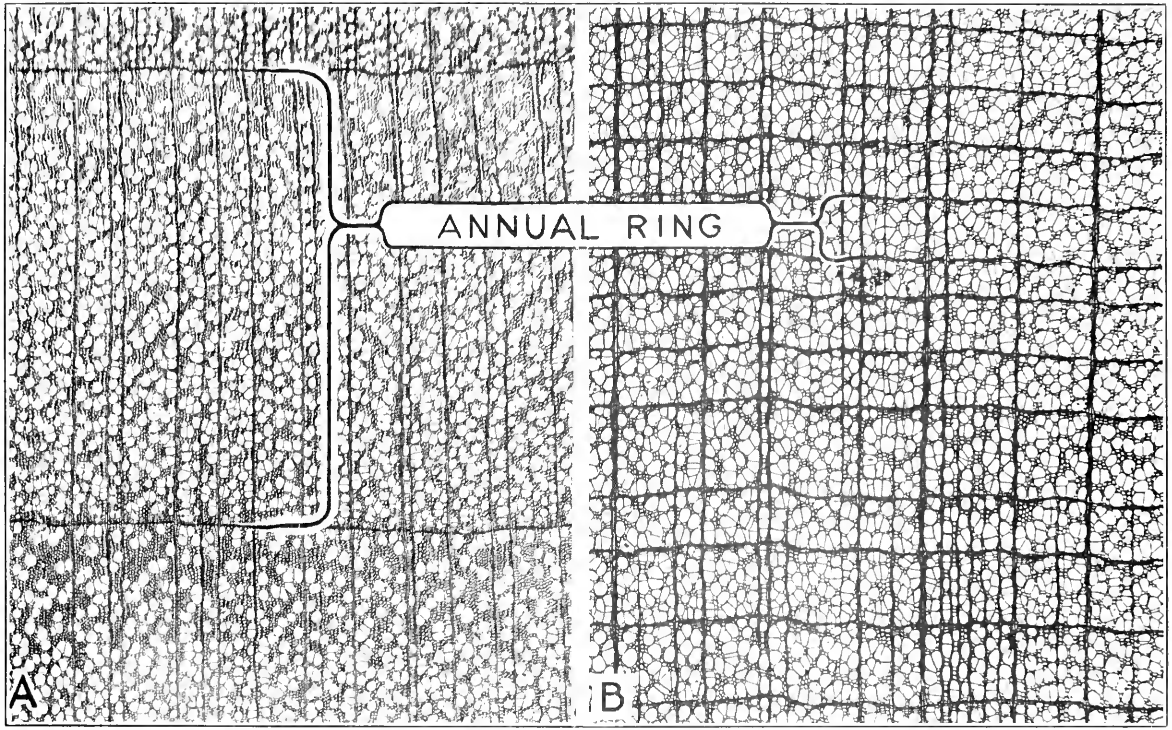


M1902F

COMPARISON OF GROWTH AND OF SPECIFIC GRAVITY IN CROSS SECTIONS OF SUGAR MAPLE

A. Produced wood of high specific gravity until the period of maximum rate-of-diameter growth was reached. Afterwards, as the result of crowding and the reduction of the crown size, the specific gravity decreased.

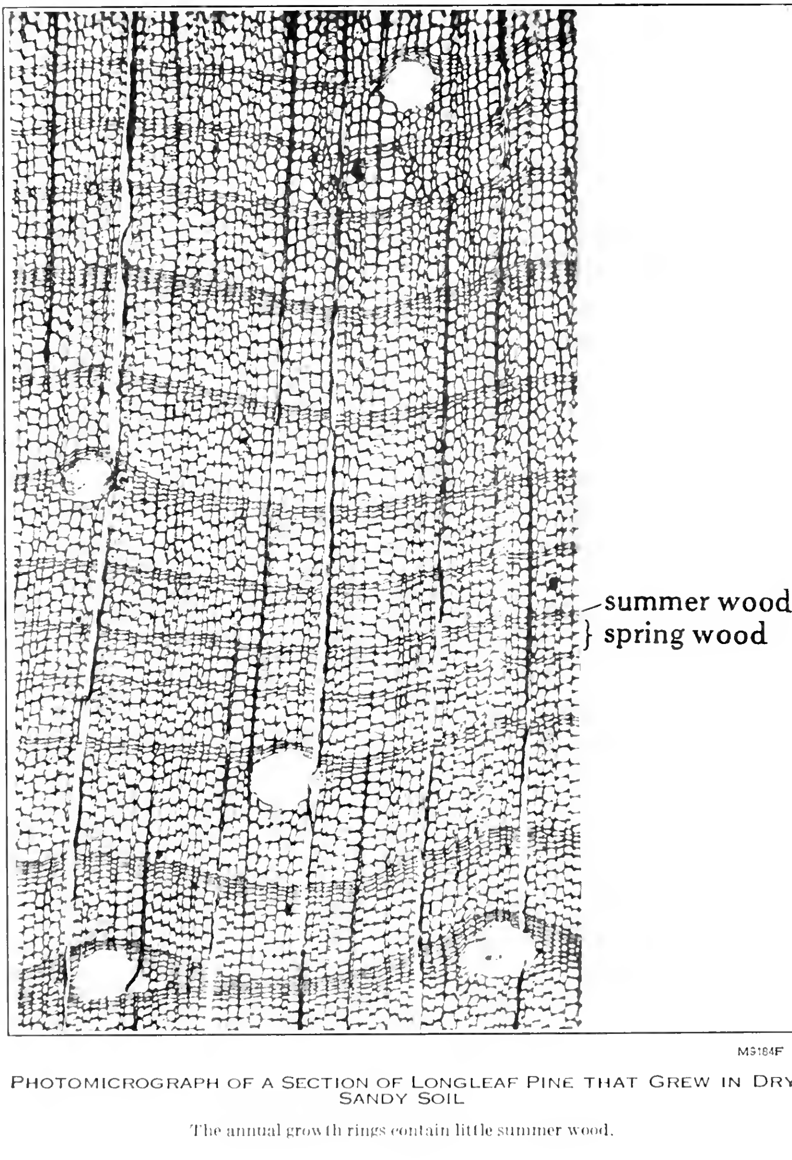
B. Enjoyed more growing space, developed a larger crown, maintained rapid diameter growth, and produced wood of uniformly high specific gravity.



M2676; M2677

COMPARISON OF THE STRUCTURE OF WOOD PRODUCED DURING THE PERIODS OF RAPID AND OF SLOW GROWTH IN A YELLOW POPLAR TREE

A.—Has a specific gravity of 0.41 and was produced during the early life of the tree, while it enjoyed sufficient growing space.
B.—Was produced after the tree had suffered reduction of crown as a result of many years' crowding in the virgin forest; this wood has a specific gravity of only 0.31.



M9184F

PHOTOMICROGRAPH OF A SECTION OF LONGLEAF PINE THAT GREW IN DRY SANDY SOIL

The annual growth rings contain little summer wood.

conforming to the time during which the growth of the trees was suppressed. The last period of growth in these trees showed a renewed activity in the rate of diameter growth resulting from the removal of some of the surrounding trees and a definite average increase in the specific gravity of the wood. (Pl. 3, A.) The specific gravity determinations for the wood from the second wood lot gave uniform results throughout the lives of the trees. These trees were grown under continued favorable conditions of soil and growing space in a wood lot in southern Michigan. As a result of selective cutting in this stand the trees continued to make rapid growth in diameter and at 200 years of age were producing wood practically as heavy as at any previous time. (Pl. 3, B.)

SUGAR MAPLE

Samples of sugar maple (*Acer saccharum*) were collected from wood lots in southern Michigan, in northern Ohio, and in the Adirondack region of New York. Specimens from 44 trees were selected from eight localities. The trees were divided into two groups, those showing a decreasing rate of diameter growth with advancing age and those maintaining the initial rate of this growth.

The reaction of the wood of sugar maple to crowding in the stand is shown in the specific gravity results recorded in the first group of Table 5.

TABLE 5.—*Average specific gravity values for successive growth periods in sugar maple trees*

Wood lot No.	Trees	Average age	Initial growth period		Final growth period	
			Annual rings per inch	Specific gravity	Annual rings per inch	Specific gravity
Group 1:	*Number*	*Years*	*Number*		*Number*	
1	3	180	24	0.692	26	0.623
2	4	95	15	.703	20	.660
4	7	133	18	.685	24	.630
5 and 6	4	145	18	.691	26	.644
Average			19	.693	24	.634
Group 2:						
1	2	165	25	.701	18	.686
2	2	84	14	.727	17	.702
3	6	152	27	.708	17	.688
5 and 6	6	130	17	.731	12	.704
7	5	82	11	.690	14	.675
8	5	56	12	.683		
Average			18	.708	16	.691

While the results of the specific gravity determinations show that the wood of the sugar maple trees investigated is affected by crowding in the same manner as the ash, hickory, and rock elm trees studied, the changes take place less abruptly. This may be due to the fact that the sugar maple trees usually occupied the better soils and also that sugar maple is especially tolerant of shade. A comparison of the specific gravity of the wood formed up to and including the time of most rapid growth in diameter with that of the wood formed during periods of subsequent retardation of diameter growth shows a lower specific gravity of the wood for the periods of retardation in trees from all of the wood lots investigated.

The wood produced during the initial growth periods, even though of slow growth, and the wood produced during periods of maintained or of accelerated rate of growth in diameter were the heaviest, while the wood produced during the periods of decreasing growth always had a somewhat lower specific gravity than that in the preceding period. (Pl. 4.)

No sugar maple that exhibited the results of thinning a crowded stand was collected but it is believed that this species would not be different in this respect from the species already discussed or from the yellow poplar which is considered later. Sugar maple trees with sufficient growing space continued to maintain a fairly rapid rate of growth in diameter and to produce wood layers of uniformly high specific gravity.

The European red beech, also a diffuse-porous species like sugar maple, has been found by Hartig to respond by faster growth and heavier wood to thinning in the stand. In his work on this beech (*Fagus sylvatica*) (*10*), Hartig includes specific gravity results for different periods in the life of two trees taken from a 150-year-old stand that had been heavily thinned seven years previously. The average specific gravity of the wood formed in these trees during a 23-year period just before the thinning was 0.60, whereas that of the wood formed in the same trees during the 7-year period following the thinning had an average value of 0.70, and although the rate of volume growth of these trees had been falling off before the thinning, it increased fourfold as a result of giving the trees more growing space.

YELLOW POPLAR

The wood of yellow poplar (*Liriodendron tulipifera*) was investigated as a second example of a species with diffuse-porous structure. The material used was obtained from forests in northern Georgia, in western North Carolina, and in West Virginia. Twenty-five trees, including both virgin growth and second growth, were cut.

The yellow poplar trees studied gave wider variations in specific gravity than the sugar maple trees, but like the latter, they showed less abrupt changes in specific gravity with the first retardation of the growth rate than the typical ring-porous species investigated. But whenever prolonged suppression of growth occurred, the severity of the suppression was reflected in a lowering of the specific gravity of the wood. (Pl. 5.) Similarly, old virgin-growth trees responded readily to improved conditions of growth effected by a thinning of the original forest stand.

The wood of the second-growth yellow poplar trees was heavier than that of the old virgin-growth trees, which had struggled for many years under the crowded conditions of the original forest. In the second growth the wood of 14 trees under 150 years of age had an average specific gravity of 0.460 while that of 11 older virgin-growth trees averaged only 0.426.

The influence of improved growth conditions upon the rate of growth and upon the specific gravity of the wood of virgin-growth yellow poplar trees in the mountains of West Virginia is shown in Table 6.

TABLE 6.—*Average specific gravity for successive periods in the growth of yellow poplar trees*

Trees	Average	Period of initial growth		Intermediate period of suppression		Final period of accelerated growth	
		Annual rings per inch	Specific gravity	Annual rings per inch	Specific gravity	Annual rings per inch	Specific gravity
Number 4	*Years* 280	*Number* 18.2	0.403	*Number* 34.1	0.379	*Number* 19.8	0.402

RELATION OF SPECIFIC GRAVITY TO THE STRUCTURE OF THE ANNUAL RING IN HARDWOODS

In the ring-porous species studied, a retardation of the rate of growth in diameter brought the rows of large open pores in successive annual rings, as seen in cross section, closer together by a reduction in the development of the portion of the ring containing the thicker-walled summer-wood cells. This reduction resulted from unfavorable growth conditions during the summer and consequently affected the summer wood more than the spring wood. The net result was wood with a greater than normal proportion of the porous spring wood, which caused a lower specific gravity.

In the diffuse-porous woods studied, less contrast existed in the portion of the annual rings formed during the early and during the later parts of the growing season, so that the first gradual retardation of radial growth may not be reflected in the specific gravity of the wood. A continuation of adverse growth conditions, however, resulted not only in the formation of narrower rings but also in the formation of rings more porous, so that the wood became correspondingly lighter. In the ring-porous ash and hickory and in the diffuse-porous sugar maple and yellow poplar, the result was essentially the same and doubtless depends upon the same principles of growth.

CONCLUSIONS

From the preceding investigations of broad-leaved species it is apparent that wood having the most uniform properties and the highest quality with respect to both strength properties and freedom from defects is produced, in the hardwoods, when the trees are grown sufficiently close together while young to cause removal of lateral branches, and are subsequently thinned sufficiently to maintain or increase the rate of diameter growth of the trees. Where dry sites or soils low in fertility are involved, the silvicultural treatment should also aim to benefit the water-holding capacity and the fertility of the soil.

Forest management may not anticipate a maintained or increased rate of diameter growth throughout the entire rotation, a maintained volume increment being all that is desired. However, with species such as hickory and ash, where the strength of the wood is of paramount importance, the additional effort required to maintain the rate of diameter growth up to a practical rotation period should be well worth while.

INVESTIGATIONS OF CONIFEROUS SPECIES

There is much confusion of opinion in regard to the relation between growth factors and the properties of wood in broad-leaved species and in conifers. This is perhaps due primarily to the differences in structural arrangement of the elements in the annual growth rings in the two classes.

The coniferous annual ring, typified by species like the hard pines, redwood, and Douglas fir, consists of two distinct parts, the spring wood and the summer wood. These parts are somewhat comparable to the parts of the ring of the ring-porous hardwoods except that they are more variable in width. The spring wood consists of thin-walled cells, whereas the summer wood cells are thick walled. As in the ring-porous hardwoods, the total weight of the wood is influenced by the relative proportion of the two kinds of wood layers present. Both very wide and very narrow annual rings in conifers usually contain a larger proportion of the spring-wood layer, so that in these species wood representing either extreme of growth may be low in specific gravity. The wood of intermediate growth rate is usually the heavier.

The fact that conifers usually grow on lighter soils than the hardwoods may somewhat influence the relation between the width of the annual rings and the specific gravity, but there seems to be no doubt that the relationship between rate of growth and specific gravity differs in the conifers and hardwoods. This is shown by the generally recognized superiority in strength of the rapidly grown second-growth hickory as compared to virgin-growth hickory and the inferiority in strength of the rapidly grown second-growth southern pine as compared to virgin-growth southern pine.

THE SOUTHERN PINES

In the study of the southern pines that was begun in 1925, specimens were obtained from 380 trees collected from 55 stands, representing the region from New Jersey to Texas. The species included are longleaf (*Pinus palustris*), shortleaf (*P. echinata*), loblolly (*P. taeda*), and slash pine (*P. caribaea*).

The principal phases of the southern pine study were: (1) A comparison of the specific gravity of the wood from virgin-growth and from second-growth trees; (2) an investigation of the influence of closeness of stocking of the stand and of thinnings upon the specific gravity; and (3) to some degree, the effect of the moisture conditions and the fertility of the site upon the specific gravity of the wood.

COMPARISON OF VIRGIN-GROWTH AND SECOND-GROWTH SOUTHERN PINE

The specific gravity of the wood of some second-growth stands equaled that of virgin-growth stands while in others it was lower. In both kinds of stands, variations in specific gravity were found that reflected the influence of the environmental conditions on the trees in the stand at different periods in the lives of the trees.

As a rule, the virgin-growth southern pines contained wood of low specific gravity in the very narrow slow-growth annual rings in the outer portions of the boles and wood of comparatively high specific gravity in the central portions representing an intermediate rate of growth. Exceptions were found in the trees that had made very rapid growth in early life and as a result possessed wide rings of low specific gravity near the center.

In the second-growth trees, however, the wood of low specific gravity was contained in the wide growth rings usually occupying the central portion of the trees. This was especially true in stands where the trees started with plenty of growing space and then crowded each other as they increased in size. The smallest variation in specific gravity in the cross section of second-growth southern pine was found in trees from fairly open stands. A fair comparison of virgin-growth and second-growth southern pine must therefore be made on the basis of the character of the stand. The wood of a medium-growth rate in well-stocked second-growth stands was as heavy as the best wood from virgin-growth trees, as may be seen in Table 7.

TABLE 7.—*Comparison of rate of growth and of average specific gravity for successive growth periods in virgin-growth and in second-growth stands of longleaf pine*

Locality	Growth	Trees	Range in age	Initial growth period		Intermediate growth period		Final growth period	
				Annual rings per inch	Specific gravity	Annual rings per inch	Specific gravity	Annual rings per inch	Specific gravity
		Number	*Years*	*Number*		*Number*		*Number*	
Walton County, Fla.	Virgin	6	100–220	19	0.680	31	0.592	42	0.481
Smith County, Miss.	do	10	125–350	16	.670	19	.617	30	.508
Vernon Parish, La.	do	5	100–200	14	.644	33	.620	49	.490
Richland County, S. C.	do	4	100–140	16	.628	24	.535	21	.521
Berkley County, S. C.	do	5	120–150	25	.609	42	.531	27	.533
Do	do	5	60–140	20	.638	11	.589	15	.581
St. Tammany Parish, La.	Second	5	90	11	.674	14	.643	18	.652
Columbia County, Fla.	do	5	35	4	.505			8	.561
Charleston County, S. C.	do	10	45	5	.545	6	.550	12	.581
Clay County, Fla.	do	5	25	3	.546			5	.529
Do	do	5	30	5	.546			14	.694
Do	do	5	30	5	.539			9	.590

THE INFLUENCE OF CLOSENESS OF STOCKING AND THINNINGS

The trees from open second-growth southern pine stands developed very large and spreading crowns which often covered a considerable portion of the length of the bole. An examination of the wood from such trees usually reveals very wide growth rings containing a large proportion of spring wood that merges into summer wood so gradually that no definite point of change can be determined in the ring. Wood of this type is, as a rule, light in weight, the weight depending upon the proportionate amount of summer wood present.

In contrast with the wood from sparsely stocked stands, small-crowned trees from fully stocked areas in the same forest, often only a few rods distant, contained wood that was much heavier. In these areas the rate of growth of the individual trees was slower; the proportion of spring wood in the annual growth rings was less; there was an abrupt line of demarcation between the spring-wood portion and the summer-wood portion of the annual growth ring; and the total proportion of summer wood, as measured on a radial line in cross section, was greater. Contrasts of this type were found in second-growth stands of the four species of southern pine studied. The results of the specific gravity determinations are given in Table 8.

TABLE 8.—*Comparison of crown size and of average specific gravity of the wood of second-growth southern pine trees in stands of different density on the same forest area*

Species	Locality	Trees	Character of stand	Rate of growth (annual rings per inch)	Average specific gravity of trees with—	
					Large crowns	Small crowns
		Number		*Number*		
Loblolly pine	Louisiana	5	Fully stocked	9		0.496
Do	do	10	Open stand	2	0.388	
Do	South Carolina	5	Dense stand mixed with hardwoods.	6		.472
Do	do	10	Open stand	3	.423	
Shortleaf pine	Arkansas	5	Fully stocked	11		.502
Do	do	5	Open stand	7	.457	
Do	Texas	5	Fully stocked	11		.566
Do	do	5	Medium open	6	.496	
Slash pine	Florida	5	Dense stand mixed with hardwoods.	11		.596
Do	do	5	Very open	3	.507	
Longleaf pine	Texas	5	Fully stocked	11		.580
Do	do	5	Medium open	5	.537	
Do	Florida	5	Fully stocked	9		.620
Do	do	5	Medium open	4	.538	

It is evident from this phase of the study that the proportionate amount of spring wood in the annual ring is influenced largely by the crown size. The development of the summer wood portion, however, appears to depend more upon favorable conditions for continued growth throughout the season.

Investigations of thinned stands of southern pine and of trees left in logging revealed a great increase in the rate of growth in diameter after such thinnings. The wood of faster-growth rate produced after the thinning was sometimes heavier but more often the production of spring wood was proportionally so much greater than summer wood that lighter wood resulted. Some comparisons of the specific gravity of wood in the same trees, representing the wood before and subsequent to thinning, are given in Table 9.

TABLE 9.—*Comparison of rate of growth and average specific gravity of the wood of southern pine before and after thinning*

Species	Locality	Trees	Average age	Initial growth period		Intermediate growth period		Final growth period, after thinning	
				Annual rings per inch	Specific gravity	Annual rings per inch	Specific gravity	Annual rings per inch	Specific gravity
		Number	*Years*	*Number*		*Number*		*Number*	
Longleaf	LaSalle Parish, La	7	125	20	0.669	33	0.626	11	0.612
Do	Walton County, Fla.	5	100	28	.636	43	.600	13	.637
Shortleaf	Moore County, N. C.	5	55	10	.521	37	.567	16	.551

THE EFFECT OF MOISTURE CONDITIONS AND THE FERTILITY OF THE SITE UPON THE SPECIFIC GRAVITY OF THE WOOD OF SOUTHERN PINES

The reason for the formation near the perimeter of the old virgin-growth trees of narrow annual rings, containing relatively light wood, has not yet been positively determined. Several factors may be involved. An examination of these extremely narrow annual rings showed that they are greatly lacking in summer-wood development. (Pl. 6.) Perhaps an insufficient water supply during the summer accounts for the lack of summer wood. During years of extreme drought, the development of the summer-wood portion of an annual ring is very much below that formed in a season of usual rainfall, even though the spring-wood development for the same years is practically normal. But these virgin-growth trees were also lacking in spring-wood development, which indicates some other factor. Possibly the site had become deficient in one or more of the plant-food elements required for tree growth. Frequent forest fires may have decreased the soil fertility and lowered the moisture-holding capacity of the soil, thus causing an almost complete cessation of growth.

Further evidence of the importance of water and of soil fertility in the production of summer wood in the annual ring was found in a comparison of the wood of shortleaf pine trees grown on dry sandy land with that grown on clay loam soils. The wood of the shortleaf pine trees from the sandy site averaged 15 per cent lower in specific gravity than the wood of the same species growing on heavier and more moist soils. (Pl. 7 and Table 10.) Wood of slower growth and lower specific gravity directly attributable to surface burning of the site was found in shortleaf pine formed during a 17-year period in which the area about the trees was burned annually, and as compared to wood produced in the same trees previous to the burning, and also as compared to wood produced during the same years in near-by trees of the same species growing on an adjacent unburned area. (Pl. 8.) During the period of burning there was a considerable decrease in the rate of the growth of the trees, and the wood produced was 6 per cent lower in specific gravity than that produced during the same years in trees on the unburned site.

TABLE 10.—*Comparison of average specific gravity for second-growth shortleaf pine from different types of soil*

Type of soil	Trees	Age class	Average height	Initial growth period		Intermediate growth period		Final growth period		Average specific gravity for site
				Annual rings per inch	Specific gravity	Annual rings per inch	Specific gravity	Annual rings per inch	Specific gravity	
	Number	*Years*	*Feet*	*Number*		*Number*		*Number*		
Light gravelly sand	10	60-70	50	8	0.459	15	0.446	36	0.458	0.454
Red clay loam	10	60-70	75	5	.489	11	.536	17	.566	.530
Do	10	50-60 60-70	65 70	8	.514			13	.560	.537

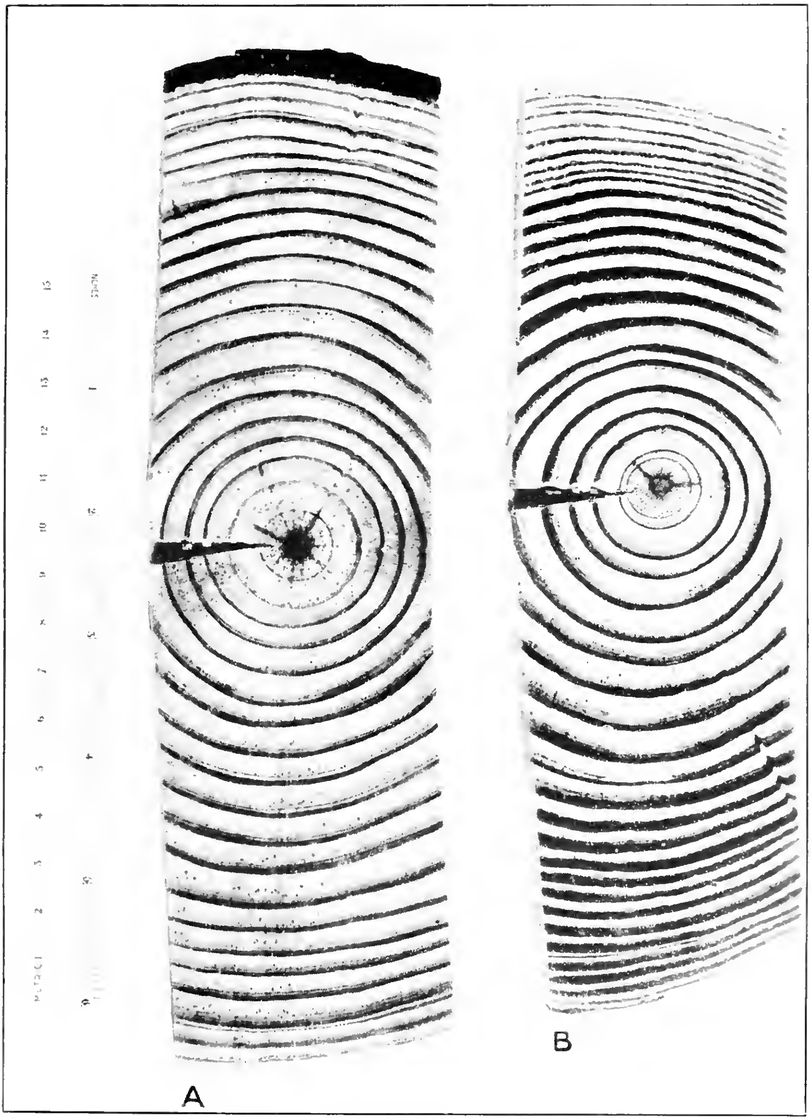
It has been pointed out that the specific gravity of the wood of the southern pines depends to a great extent upon the relative amount of spring wood and summer wood present in the annual rings. Since the strength of southern pine, as in the hardwoods, is closely related to its specific gravity, the question of controlling the proportion of the heavier summer wood by silvicultural methods becomes of interest.

FACTORS INFLUENCING SPRING WOOD AND SUMMER WOOD DEVELOPMENT IN THE SOUTHERN PINES

As already pointed out, the wide annual rings (Table 8) from second-growth trees having relatively large crowns contained very broad bands of spring wood and rather narrow bands of summer wood. Also in the wider rings there is usually a very gradual change from one type of wood into the other, a change far more gradual than that in narrow rings. On the other hand, in the trees that originated in very dense stands, where the crown development of the individual trees was restricted, comparatively narrow spring wood bands and proportionately broader summer wood bands were formed in the annual rings. It appears from the rate of growth near the center of the trees that most of the virgin-growth southern pine stands originated under fairly crowded forest conditions; this may be one explanation of the differences in the specific gravity of the wood in virgin-growth and in second-growth southern pine stands.

REDWOOD (SECOND GROWTH)

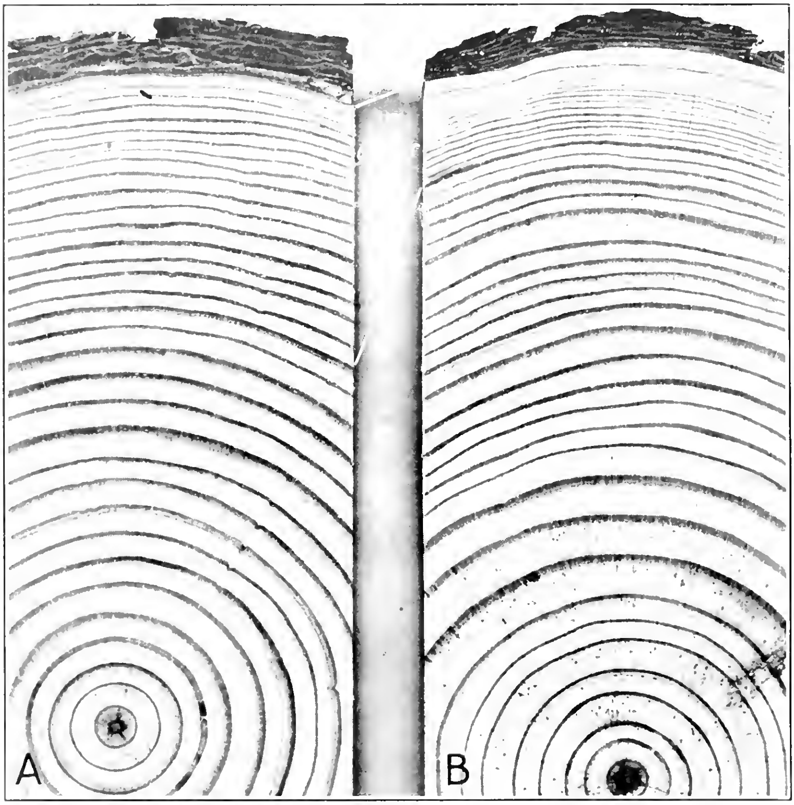
Investigations of the influence of growing space in second-growth redwood (*Sequoia sempervirens*) (*14*) show that the relations found in respect to trees with large crowns and small crowns in the southern pines hold also in redwood. Wood was taken from large-crowned trees in a sparsely stocked area and from small-crowned trees in a densely stocked area of the same second-growth forest near Eureka, Humboldt County, Calif. Compressive strength tests (parallel to the grain) were made on the same sticks that were used for the specific gravity determinations. The specific gravity and compressive strength values of both types of second-growth redwood trees are presented in Table 11. The wood from trees in the more dense stands has a higher specific gravity and is stronger in compression than the wood from trees in open stands.



M7305F

CROSS SECTIONS OF TWO LONGLEAF PINE TREES

A.—From high ground.
B.—From a low, moist situation. The tree from the moist situation produced wider summer-wood bands in individual annual rings and wood of greater density.



M3016F

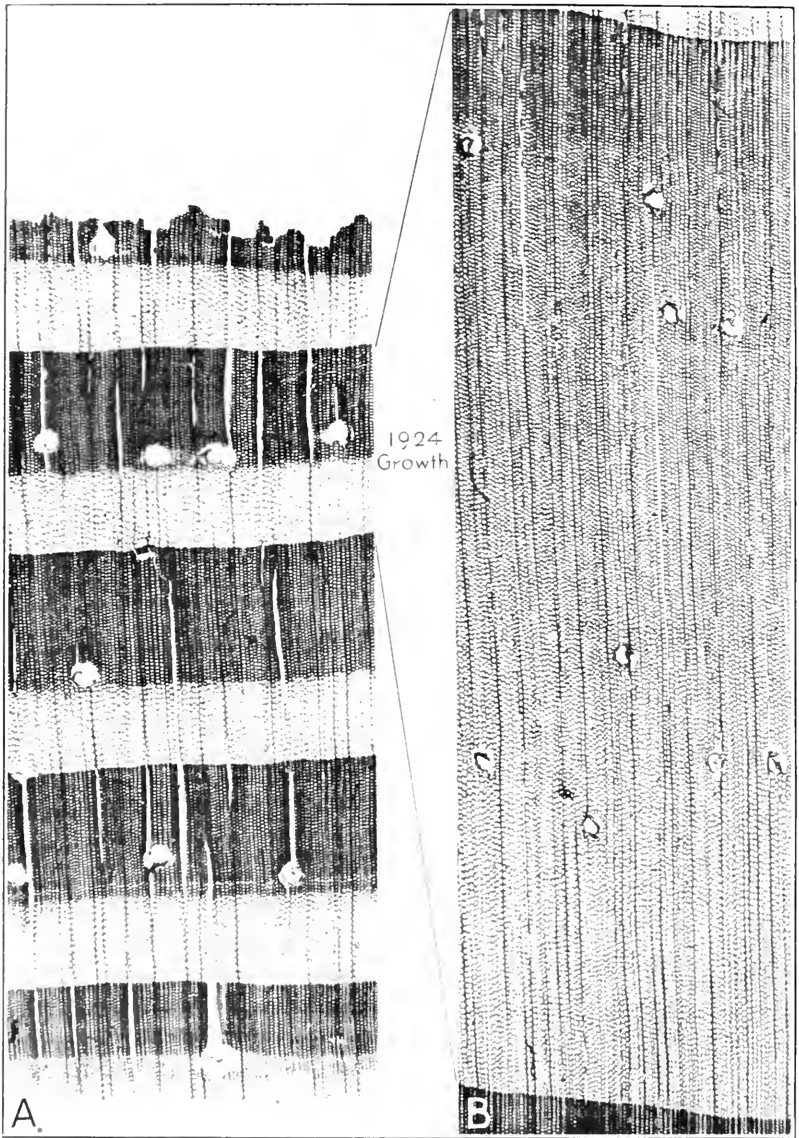
THE DISASTROUS EFFECT OF FIRE ON TREE GROWTH

A. Was not in burned area and grew faster with more summer wood.
B. Was located on an area burned over annually during a 17-year period prior to cutting. The two trees grew only a few yards apart.

M7304F

ADJACENT LONGLEAF PINE STANDS THAT WILL PRODUCE, RESPECTIVELY, DENSE AND NONDENSE WOOD

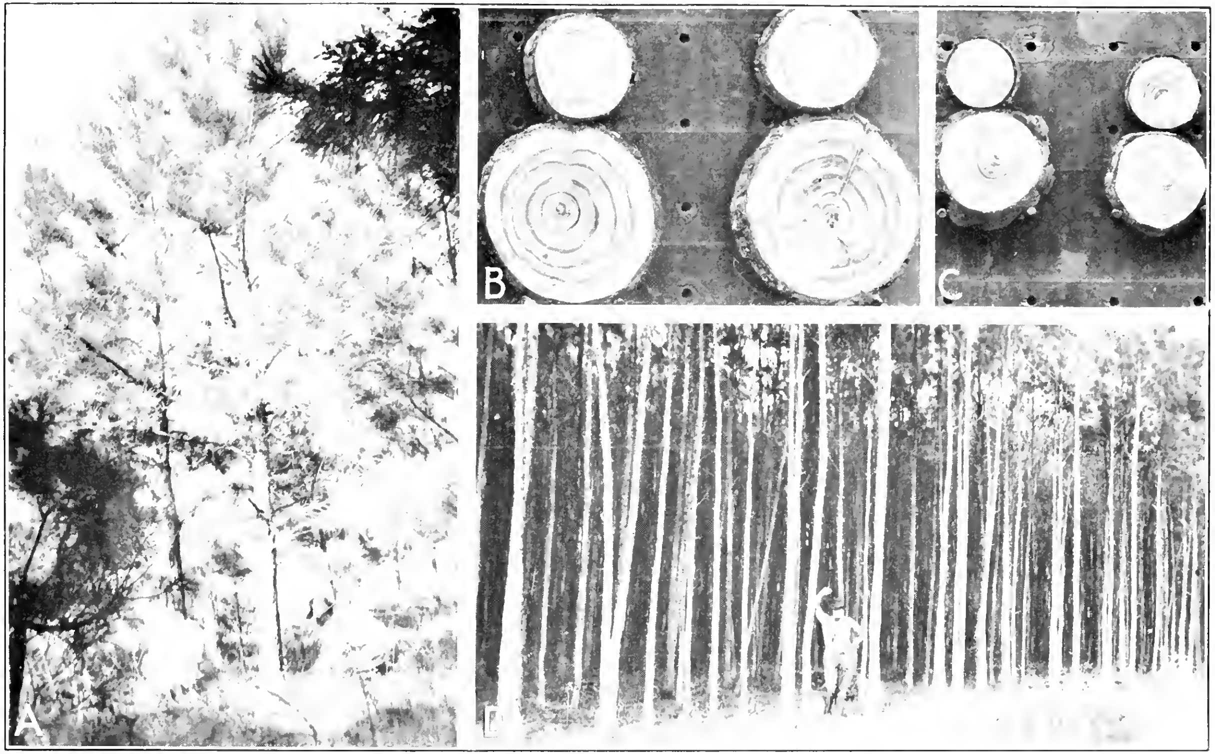
A.—Cross sections of trees from stand B, showing denser wood in the outer rings, formed during the period of restricted crown development.
D.—Cross section from large-crowned tree from stand C; this wood is of relatively low density.



M7303F

A PHOTOMICROGRAPHIC COMPARISON OF THE STRUCTURE OF THE 1924 ANNUAL RINGS IN TREES REPRESENTING THE TWO TYPES OF GROWTH CONDITIONS IN PLATE 9

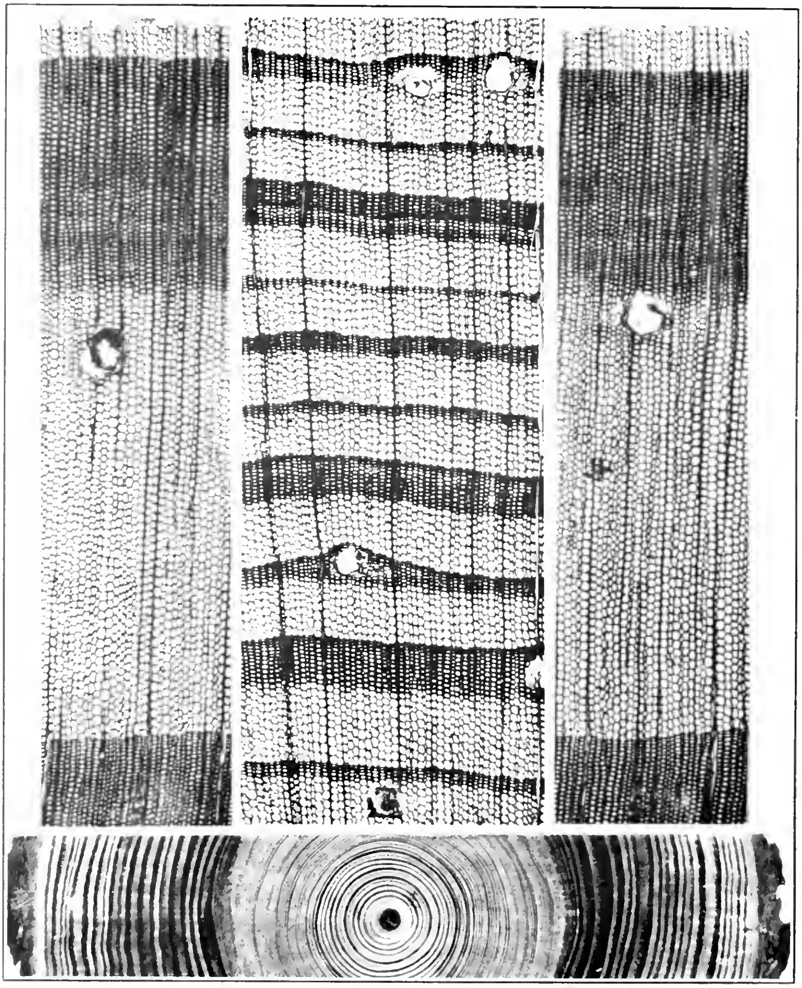
A.—Cut from the fully stocked stand and shows relatively small spring wood.
B.—Was taken from the open stand, and spring wood is abundant, but it merges into summer wood so gradually that no definite point of change can be determined in the ring. The trees from which these sections were cut grew within a few rods of each other.



M7301F

TYPES OF GROWTH AND THE RESULTING WOOD OF LOBLOLLY PINE CONTRASTED

B.—Rapid-growth wood from the large-crowned trees of A.
C.—Slower growth and more dense wood from the stand shown in D. Stand A is 7 years old; stand D, 18. The two grew very close to each other and all conditions, excepting the growing space of the individual trees, are nearly equal.



M7302F

THE THREE PHOTOMICROGRAPHS ARE FROM THE CROSS SECTION OF THE PINE TRUNK DIRECTLY BELOW

The middle photomicrograph shows slow growth, due to thick stands; the outer photomicrographs show fast and suitable growth, made possible by thinning.

Table 11.—*Relation of growing space and of crown development to the specific gravity and the compressive strength parallel to the grain of second-growth redwood*

Trees	Crown development and growing space	Anual rings per inch	Average specific gravity (oven-dry) based on weight and volume when green	Average compressive strength parallel to grain—	
				In green condition	In air-dry condition (5.5 per cent moisture content)
Number		*Number*		*Lbs. per sq. in.*	*Lbs. per sq. in.*
8	Trees with large crowns in open portion of stand	2.9	0.30	2,490	5,420
10	Trees with smaller crowns from more densely stocked portions of stand	8.4	.35	3,430	7,110

The difference in specific gravity presented in Table 11, caused by difference in growing space on the same area, is greater than the average difference in the specific gravity of close-grown second-growth redwood trees from the best and the poorest sites on which the species grows. The quality of the respective sites was determined on the basis of age and of height growth of the stand. While fertility of the site apparently has an important relation to the rate of height growth of the trees, the rate of diameter growth in the early decades of the life of a tree is more closely related to its crown development. Thus the open-growth second-growth redwood trees have increased in diameter nearly three times as fast as the more closely grown trees.

A comparison of the structure of the wide and the narrow annual rings in the sections reveals the fact that in the large-crowned open-grown trees a much greater proportion of the annual ring is occupied by spring wood—the lighter-weight and weaker part of the wood—than in the more narrow annual rings from the trees with the smaller crowns.

CONCLUSIONS

From the investigations of the southern pines and second-growth redwood it may be concluded that:

During the early years of the coniferous stands studied the size of the individual tree crown appears to be the principal factor in determining the specific gravity of the wood.

The young southern pine and redwood trees with large crowns growing in fairly open stands produced greater amounts of spring wood than summer wood in the annual rings, while trees of similar age with small crowns growing in fairly dense stands produced more nearly equal amounts of spring wood and of summer wood. (Pls. 9, 10, and 11.)

Where crowding in a southern pine stand had resulted in a decline in the specific gravity of the wood, a thinning either caused a subsequent increase in rate of growth in diameter accompanied by a remarkable increase in specific gravity when all of the growth conditions in the stand were especially favorable, or such a thinning caused a decrease in the specific gravity of the wood when the growth conditions were apparently more favorable to the production of spring wood than summer wood. (Pl. 12 and Table 9.)

The closely crowded trees on the good sites continued to produce wood of high specific gravity under conditions of crowding that greatly reduced the growth rate. In such trees the proportion of summer wood was relatively high.

Heavy wood in the open stands of southern pine was produced when the conditions of soil moisture and of soil fertility were such that the trees continued to grow throughout the vegetative season sufficiently to maintain a high proportion of summer wood in the annual growth rings.

The second-growth shortleaf pine growing on a very dry site produced wood of much lower specific gravity than that of the other second-growth shortleaf pine stands investigated.

THE APPLICATION OF THE RESULTS

The results of the foregoing investigations show that the regulation of growing space is the silvicultural tool which the forester can use most easily in controlling the specific gravity of wood. The species studied show a ready response to changes in the condition of the stand, whether it be crowding or thinning. This response, therefore, can be used to advantage in silvicultural management.

In all of the broad-leaved species investigated severe crowding in the stands resulted in a decrease in the specific gravity of the wood, while relief from crowding was always accompanied by an increase in specific gravity. In addition, the production of wood of uniformly high specific gravity was concurrent with a well-sustained, usually a fairly rapid, growth rate, so that in future crops of species, such as ash and hickory, the trees may be brought to merchantable maturity in a comparatively short rotation—one of perhaps 50 to 60 years.

In coniferous species, such as the southern pines and redwood, the control of specific gravity by the influence of growing space must be dealt with somewhat differently than with the broad-leaved species. In these species the specific gravity of the wood depends principally upon the relative proportions of spring wood and summer wood in the individual annual growth rings. In the second-growth stands of southern pine and redwood, the spacing of the trees had a distinct influence upon the width of the spring-wood portion of the growth ring; this portion being much narrower in the small-crowned trees of crowded stands. In trees growing under this condition the amount of summer wood was proportionately greater, and the wood accordingly heavier, but the growth rate was slower than in the trees of the more open stands. Thus, in these species the production of timber having very high strength properties requires a longer rotation than the production of timber having lower strength. For the best results, however, the stands should not be allowed to become too dense, since in that event the production of summer wood will be curtailed. In order to produce timber of high strength in the shortest possible time it will be necessary to thin the stands carefully, to prevent forest fires, and to maintain as good soil conditions as possible during the life of the stand. Thus, quantity and quality production are apparently combined on the more fertile sites.

Improvement of the soil is suggested as a means of improving wood quality. The prevention of forest fires in the southern pines should increase the organic content of the soil, furnish nitrogen in the process of decomposition, and increase the retention of soil moisture. Improvement of conditions in regard to these factors should increase the production of summer wood in the annual growth ring.

To produce light wood in second-growth southern pines and redwood, relatively wide spacing of the trees throughout the entire period of growth is required. The individual trees will then have larger crowns, more knots, shorter clear boles, and a higher percentage of sapwood, but to offset these disadvantages it will be possible to grow a tree of a specified diameter in a much shorter time.

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TESTS OF LARGE TIMBER COLUMNS AND PRESENTATION OF THE FOREST PRODUCTS LABORATORY COLUMN FORMULA

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UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

TESTS OF LARGE TIMBER COLUMNS AND PRESENTATION OF THE FOREST PRODUCTS LABORATORY COLUMN FORMULA

By J. A. NEWLIN,[1] *Principal Engineer in Charge*, and J. M. GAHAGAN, *Assistant Engineer, Section of Timber Mechanics, Forest Products Laboratory,*[2] *Branch of Research, Forest Service*

CONTENTS

SUMMARY

Producers and users of timber in the United States are concerned with the most efficient utilization of the available supply. This requires proper selection of the material for structural purposes and proper design of the structure. The value of timber is determined by its usefulness which, in turn, depends on its properties and on the completeness of its utilization. In the structural field, timbers are valued for stiffness, ability to sustain compressive stresses, appearance, capacity to take preservatives, seasoning characteristics, and a number of other properties or combinations of properties.

The results of the tests on large structural timbers presented in this bulletin together with other test data show that knots do not seriously affect the stiffness of timbers, columns, or joists. For structural members in which stiffness rather than strength is the controlling factor, such as posts in small dwellings, it is entirely safe to use

[1] The tests reported in this bulletin were made possible through the cooperation of the National Lumber Manufacturers' Association, which provided the timbers necessary for this study and to whose staff a mark of appreciation is due. Acknowledgment is particularly made to the following for their valuable assistance in the selection of the timbers: J. E. Jones, chief inspector of the Southern Yellow Pine Association; C. J. Hogue and L. P. Keith of the West Coast Forest Products Bureau; and C. W. Zimmerman, formerly of the Forest Service. The authors are especially indebted to H. S. Grenoble, formerly of the Forest Products Laboratory, for his part in conducting the tests and analyzing the test data reported in this bulletin.

[2] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

knotty material. This information, if properly made use of, will increase the outlet for low-grade stock, which the lumberman always finds difficult to move, thereby increasing the returns from the forest.

Furthermore, a simple formula for computing accurately the strength of wooden columns commonly used in buildings, bridges, and other structures has been worked out by the Forest Products Laboratory and its application demonstrated in tests on 12 by 12 inch by 24-foot timbers provided by the National Lumber Manufacturers' Association. The employment in design by engineers and architects of this formula will eliminate the use of needlessly high factors of safety in column design with the accompanying use of timbers larger than necessary. The natural result of this more economical use of structural timber will be reflected in lowering the costs of wooden construction to the builder and consumer, in opening markets for low-grade material, and in lessening the waste of our forests.

In order that the type of column to which the formula applies may be understood, it should be stated that for building purposes three types of column are recognized—long columns, which depend for their strength on stiffness; short columns, which depend for their strength upon crushing strength in direction of length; and intermediate columns, which depend on a combination of stiffness and crushing strength. The Forest Products Laboratory formula applies to intermediate columns, which are the ones used most frequently in structural work.

The formula does not require any further knowledge of mathematics than is necessary to solve the straight-line formulas now used by many engineers. In addition, the formula will enable the selection of columns that will maintain the correct load rather than columns whose strength is in excess of the loads for which they are intended. This very fact should bring about a greater confidence in wood as a safe building material.

An interesting feature, which has been quite generally recognized by the Forest Products Laboratory for many years and which is borne out by the column study, is the effect of knots on strength. In a short column this effect is approximately the same as removing a similar amount of clear material from the cross section, and the combined effect of all the knots in any 6 inches of length is approximately the same as if they occurred at the same height and in the same plane. In a long column, where stiffness is the controlling factor, knots have little effect on strength.

INTRODUCTION

The study of columns has in the past been confined chiefly to materials other than wood. In the tests on wooden columns, which have been made by different investigators, relatively small specimens were used and no common testing procedure was followed. Furthermore, in most of these tests no attempt was made to determine the influence of the quality of the clear wood and of the grade of the material upon the strength, the purpose of such tests being merely to arrive at simple empirical formulas for use in design. As a result, the available information on wooden columns has been so meager and so apparently contradictory that many architects and engineers have been led to doubt the practicability of formulas that represent the strength of such members with a reasonable degree of accuracy and have continued to use a high factor of safety in column design. With the increasing cost of building material, however, there has come a demand for a better understanding of the mechanical properties of wooden columns and for formulas and safe working stresses that point definitely to a more economical use of structural timbers. In consequence, the National Lumber Manufacturers' Association has cooperated with the Forest Products Laboratory in the present study of the influence of defects on column strength and in the development of column formulas.

This study is concerned primarily with structural columns, and especially with the effect of knots on the strength of such columns. The tests were planned to afford the additional information requisite to a practical study of column formulas in current use and to gain information that would serve as a basis for determining safe working stresses for structural columns. Accordingly, the tests were conducted upon southern yellow pine and Douglas fir, the two species most commonly used for structural timbers. In addition the results of previous tests upon other species have been included in the discussion.

The test apparatus provided for pin-ended bearings [3] for the intermediate length and long columns, since the influence of knots and of quality of clear wood upon the strength of a column can be determined most readily under these conditions rather than under square-ended bearings.[4] It is anticipated that the investigation of columns will ultimately include a more general inquiry regarding the influence of end conditions.

MATERIAL

In order to obtain comprehensive results for a species, it was necessary to obtain test material that was representative of the particular species studied. The test material, which consisted of one hundred and sixty 12 by 12 inch by 24-foot timbers, therefore varied from clear and dense to very knotty and light and covered the entire range in density and knots of southern yellow pine and Douglas fir timbers cut for commercial uses. The timbers of each species were selected jointly on the ground by representatives of the National Lumber Manufacturers' Association and of the Forest Service from logs cut during the winter and from others cut during the summer, the time of selection being such that the test material was delivered to the Forest Products Laboratory at intervals of approximately six months in four groups of 40 timbers each. Furthermore, the timbers in each group were selected in so far as was practicable in pairs matched with regard to defects and quality of the clear wood. When received at the laboratory, one timber of each pair was tested in the green condition and the other was air-seasoned under shelter for two years and then tested.

The southern yellow pine consisted of longleaf (*Pinus palustris*) and of other southern yellow pine species which are designated here "southern yellow pine not longleaf." The whole of this material was representative in quality of the range of pine cut in the longleaf pine belt. The Douglas fir material was representative in quality

[3] With pin-ended bearings, the end connections are free to move in one plane.
[4] With square-ended bearings the column abuts against two rigid plates.

of the range of timbers cut from the small "yellow fir," large "yellow fir," and "red fir," all of which are included in the Pacific coast type of Douglas fir (*Pseudotsuga taxifolia*).

Because of the size of the Douglas fir trees, timbers of the desired range in grade and density were easily obtained. In the southern yellow pine timbers, however, because of the small size of the trees, it was necessary to take a greater number of butt cuts. Consequently, a less even distribution in grade and density was obtained in the southern yellow pine.

METHODS OF TEST

A preliminary stiffness test of each timber was made by applying a relatively light load in bending over a 200-inch span. The long column (24 feet) was then tested as a whole after which an intermediate column (8 to 13 feet), a short column (2 feet), and a section for small, clear test specimens were cut from the apparently uninjured portions. (Pl. 1.) The long and the intermediate columns were tested under pin-ended bearings (pls. 2 and 3) and the 2-foot columns under square-ended bearings. (Pl. 4.) The test procedure conformed as far as practicable to the standard methods (*1*) [5] for conducting static tests of timber. All tests on large columns were conducted in the Forest Products Laboratory 1,000,000-pound testing machine which was especially designed for tests on large timber columns. Detailed test procedure is given in the Appendix.

RESULTS AND DISCUSSION

LONG-COLUMN TESTS

The data from individual tests of long columns of both southern yellow pine and Douglas fir, are shown in Tables 1 to 4. Tables 1 and 2 are for green material and Tables 3 and 4 for air-dry.

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[5] Reference is made by italic numbers in parentheses to Literature Cited, p. 43.

TABLE 1.—*Tests of long columns of southern yellow pine in a green condition*

Column No.	Dimensions				Moisture content	Specific gravity, oven-dry, based on volume when tested	Modulus of elasticity [1]	Stiffness; test span 200 inches, load at 0.2-inch deflection	Maximum expected column load based on stiffness test and determined by the Euler formula	Actual maximum column test load	Values adjusted to an arbitrary standard dimension of 11¾ by 11¾ inches by 24 feet		Grade [2]	General description of columns tested
	Depth	adth	Length								Adjusted test load	$\frac{P}{A}$		
	Inches	*Inches*	*Ft.*	*In.*	*Per cent*		*1,000 lbs. per sq. in.*	*Pounds*	*1,000 lbs.*	*1,000 lbs.*	*1,000 lbs.*	*Lbs. per sq. in.*		
[3] 1	11.80	11.99	23	11½	50.5	0.483	1,294	2,450	253.0	231.7	223.4	1,620	C	Many large knots (3½ inches) on four faces of upper three-fourths of length.
[3] 2	11.88	11.50	23	11⅛	28.9	.522	1,780	3,300	341.8	299.6	294.3	2,130	S	Practically clear.
3	11.95	11.77	23	10¾	31.3	.499	1,500	2,898	301.0	273.7	257.8	1,870	C	A few large knots (4 inches) in upper three-fourths of length.
[3] 4	11.81	11.91	24	⅛	46.1	.468	1,338	2,525	260.0	246.3	239.7	1,736	Cull.	Many large knots in clusters (2 to 4 inches) near middle of length.
5	11.82	11.82	23	11¼	28.3	.564	1,491	2,800	290.0	260.6	253.2	1,835	C	Many large knots (2 to 5 inches) throughout entire length.
6	12.00	11.97	24	¾	34.3	.524	1,608	3,200	328.0	310.4	287.6	2,083	S	Several knot clusters (¾ to 2 inches) near middle of length.
7	11.88	11.71	24	1/16	27.1	.636	1,841	3,475	358.0	362.0	351.3	2,545	S	A few knots on one face.
8	11.88	11.98	23	11½	35.3	.473	1,318	2,550	263.6	267.3	252.8	1,830	C	A few large knots on two faces in lower one-half of length.
9	11.94	11.84	23	10⅞	30.9	.579	1,936	3,750	389.0	[4] 412.0	386.6	2,800	S	Practically clear.
10	11.69	11.72	23	11⅞	30.6	.595	2,188	3,938	406.0	362.7	369.0	2,680	S	Clear.
21	11.89	11.96	23	11	26.5	.523	1,557	3,010	312.0	326.7	307.6	2,230	C	Many knots (1½ to 4 inches) on two faces.
22	11.88	11.78	24	⅜	30.2	.513	1,644	3,120	320.4	301.4	291.8	2,110	S	A few knots (1¾ inches) on one face.
23	11.91	11.79	23	11⅝	26.1	.522	1,687	3,230	333.5	289.6	276.5	2,000	S	Many large knots (1½ to 2¼ inches) in lower three-fourths of length.
24	11.90	11.93	24	¾	37.1	.457	1,293	2,500	256.0	255.6	243.8	1,765	S	A few knots (1 to 2 inches) on two faces in upper one-half of length.
25	11.93	11.90	24	2¼	39.6	.531	1,718	3,340	338.4	312.1	299.2	2,170	S	Clear.
26	11.87	11.84	24	¾	25.5	.624	1,758	3,350	343.0	338.7	328.0	2,375	S	Do.
27	11.95	11.72	24	3	52.8	.425	1,079	2,075	209.3	201.5	196.4	1,424	Cull.	Many large knots (1½ to 6 inches).
[3] 28	11.84	11.80	24	8¾	42.0	.510	1,494	2,812	273.2	260.8	269.2	1,950	S	Practically clear.
29	11.91	12.00	24	7½	33.8	.428	1,282	2,500	244.8	229.8	227.6	1,650	Cull.	Many large knots (1½ to 4 inches).

[1] A factor of 4 per cent has been included in the formula for modulus of elasticity to take care of the difference in shear distortion over a 200-inch span as against a 288-inch span, making it read $E=\frac{1.04PL^3}{48DI}$

[2] American Society for Testing Materials standard grades: S=select grade; C=Common grade. (See Amer. Soc. Testing Materials Standards, Vol. 27, p. 581.)

[3] Southern yellow pine, not longleaf.

[4] Actual test load reduced to 106 per cent of expected Euler load.

TABLE 1.—*Tests of long columns of southern yellow pine in a green condition*—Continued

Column No.	Dimensions: Depth	Dimensions: Breadth	Dimensions: Length (Ft.)	Dimensions: Length (In.)	Moisture content	Specific gravity, oven-dry, based on volume when tested	Modulus of elasticity	Stiffness; test span 200 inches, load at 0.2-inch deflection	Maximum expected column load based on stiffness test and determined by the Euler formula	Actual maximum column test load	Values adjusted to an arbitrary standard dimension of 11¾ by 11¾ inches by 24 feet: Adjusted test load	Values adjusted to an arbitrary standard dimension of 11¾ by 11¾ inches by 24 feet: $\frac{P}{A}$	Grade	General description of columns tested
	Inches	*Inches*	*Ft.*	*In.*	*Per cent*		*1,000 lbs. per sq. in.*	*Pounds*	*1,000 lbs.*	*1,000 lbs.*	*1,000 lbs.*	*Lbs. per sq. in.*		
[3] 30	11.97	11.85	24	5	29.7	.558	1,527	2,985	297.0	301.5	292.8	2,120	S	Practically clear.
41	11.82	11.91	24	5	34.2	.457	1,401	2,650	263.8	[4] 279.5	280.8	2,035	C	Many large knots (2½ inches) in upper one-half of length.
42	11.81	11.84	24	3/8	35.7	.480	1,225	2,300	236.0	[4] 250.0	245.2	1,780	C	Many large knots (2 to 3 inches).
43	11.78	11.86	23	11 7/8	36.9	.553	1,992	3,710	382.2	380.0	373.2	2,705	S	Many knots (1½ inches).
44	11.85	11.85	24	4 5/8	32.4	.534	1,762	3,340	333.3	[4] 353.0	352.1	2,550	S	Several small knots (1 inch) in central one-half.
45	11.84	11.88	23	10	33.8	.489	1,266	2,400	250.5	247.2	235.6	1,706	S	A few large knots (2 to 3 inches).
46	11.87	11.89	24	7/8	36.4	.532	1,945	3,720	380.7	349.6	337.2	2,442	S	A few small knots (1 inch).
47	11.81	11.75	24	6	30.2	.634	1,818	3,385	334.7	[4] 354.6	364.0	2,640	S	Clear except for pitch streaks.
[3] 48	11.89	11.89	24	4	28.2	.602	1,264	2,427	243.2	233.9	229.0	1,660	C	Many knots (1 to 4 inches).
49	11.82	11.80	24	8	33.7	.488	1,527	2,860	279.0	256.6	265.5	1,925	S	Clear.
50	11.80	11.95	24	5 3/8	37.4	.582	2,070	3,910	388.0	354.9	357.7	2,590	S	Do.
61	11.96	11.92	24	1	28.7	.536	943	1,850	189.2	187.9	177.0	1,283	C	Knots (⅞ to 4 inches) on all faces.
62	11.84	11.86	24	5/8	30.7	.600	2,112	4,000	410.0	418.4	406.8	2,950	S	Clear.
63	11.78	11.87	24	1/4	32.3	.529	1,163	2,170	223.0	[4] 236.3	232.5	1,685	C	Many knots (1 to 5½ inches) on all faces.
64	11.82	11.90	24	7/8	37.6	.508	1,678	3,170	324.2	314.7	307.2	2,225	S	A few knots (1½ to 2½ inches).
65	11.96	11.70	23	11 3/4	34.4	.565	1,482	2,850	294.0	273.3	260.0	1,885	S	Several knots (¾ to 1½ inches) in central one-half.
66	11.89	11.85	24	3/8	36.2	.504	1,526	2,920	301.2	[4] 319.2	306.6	2,220	S	One medium-sized knot in central one-third.
67	11.86	12.01	24	1	32.7	.471	1,414	2,725	278.8	265.5	254.5	1,845	S	Several knots (1 to 2¾ inches) on three faces.
68	11.90	11.98	23	11	35.3	.538	1,778	3,450	357.8	[4] 379.0	355.3	2,575	S	Clear.
69	11.98	12.02	24	3/8	34.7	.534	1,598	3,175	326.0	323.7	299.8	2,170	S	Two knots (1½ inches) near middle of timber.
70	11.82	11.91	24	3/4	29.3	.605	1,876	3,550	363.6	370.1	361.0	2,630	S	Clear.

[3] Southern yellow pine, not longleaf.

[4] Actual test load reduced to 106 per cent of expected Euler load.

TABLE 2.—*Tests of long columns of Douglas fir in a green condition*

Column No.	Dimensions				Moisture content	Specific gravity, oven-dry, based on volume when tested	Modulus of elasticity [1]	Stiffness; test span 200 inches, load at 0.2-inch deflection	Maximum expected column load based on stiffness test and determined by the Euler formula	Actual maximum column test load	Values adjusted to an arbitrary standard dimension of 11¾ by 11¾ inches by 24 feet		Grade [2]	General description of columns tested
	Depth	Breadth	Length								Adjusted test load	$\frac{P}{A}$		
	Inches	*Inches*	*Ft.*	*In.*	*Per cent*		*1,000 lbs. per sq. in.*	*Pounds*	*1,000 lbs.*	*1,000 lbs.*	*1,000 lbs.*	*Lbs. per sq. in.*		
1	11.91	11.98	24	1/16	31.6	0.441	2,131	4,150	427.0	406.3	383.0	2,770	S	Boxed heart, small yellow fir type, butt cut, many knots (¾ to 1½ inches) on all faces.
3	11.93	11.90	24	0	29.1	.412	1,712	3,325	342.3	323.2	305.0	2,210	S	Do.
4	11.96	11.89	23	11¾	32.2	.419	1,584	3,100	320.0	312.4	292.4	2,115	S	Boxed heart, small yellow fir type, top cut, many knots (¾ to 2¼ inches) on three faces.
5	11.87	11.90	24	0	31.1	.439	1,854	3,550	365.6	296.6	284.3	2,060	S	Boxed heart, small yellow fir type, butt cut, many knots (¾ to 1½ inches) on all faces.
6	11.84	11.90	24	⅛	32.0	.438	1,765	3,350	344.8	362.2	350.2	2,540	S	Boxed heart, small yellow fir type, top cut, many knots (⅜ to 2 inches) on all faces.
12	11.85	11.92	23	11¾	32.0	.447	1,519	2,900	299.0	295.6	283.8	2,057	S	Boxed heart, small yellow fir type, top cut, many knots (¾ to 2 inches) on all faces.
13	11.78	11.84	23	11⅞	33.9	.496	1,772	3,300	340.0	355.9	350.0	2,538	S	Side cut, large old-growth fir type, top portion of first 40-foot log, clear.
15	11.89	11.66	24	½	34.4	.402	1,851	3,488	357.8	309.2	302.0	2,190	S	Side cut, large old-growth fir type, top portion of first 40-foot log, a few small knots.
17	11.84	11.84	24	3/16	35.0	.440	1,508	2,850	293.0	281.6	273.3	1,980	S	Side cut, large old-growth fir type, top portion of first 40-foot log, many knots (¾ to 4¼ inches).
19	11.78	11.89	23	11¾	34.1	.425	1,859	3,475	358.4	335.2	328.2	2,380	S	Boxed heart, large old-growth fir type, top portion of first 40-foot log, many knots (¾ to 1 inch).
21	11.79	11.93	23	11⅞	37.9	.399	1,583	2,975	306.7	249.1	242.7	1,760	C	Boxed heart, large old-growth fir type, top portion of first 40-foot log, many knots (½ to 3 inches).
23	11.89	11.76	24	⅜	30.5	.483	1,249	2,375	244.0	258.2	249.8	1,800	C	Side cut, large old-growth fir type, top portion of first 40-foot log, many knots (½ to 5 inches).
25	11.66	11.96	24	⅛	36.7	.439	1,625	2,962	305.0	301.9	303.8	2,200	S	Side cut, large old-growth fir type, top portion of first 40-foot log, many knots (½ to 3½ inches).

[1] A factor of 4 per cent has been included in the formula for modulus of elasticity to take care of the difference in shear distortion over a 200-inch span as against a 288-inch span, making it read $E=\frac{1.04PL^3}{48Di}$

[2] American Society for Testing Materials standard grades: S=Select grade; C=common grade. (See Amer. Soc. Testing Materials Standards, Vol. 27, p. 581.)

TABLE 2.—*Tests of long columns of Douglas fir in a green condition*—Continued

Column No.	Dimensions: Depth	Dimensions: Breadth	Length: Ft.	Length: In.	Moisture content	Specific gravity, oven-dry, based on volume when tested	Modulus of elasticity	Stiffness; test span 200 inches, load at 0.2-inch deflection	Maximum expected column load based on stiffness test and determined by the Euler formula	Actual maximum column test load	Values adjusted to an arbitrary standard dimension of 11¾ by 11¾ inches by 24 feet: Adjusted test load	Values adjusted: $\frac{P}{A}$	Grade	General description of columns tested
	Inches	*Inches*	*Ft.*	*In.*	*Per cent*		*1,000 lbs. per sq. in.*	*Pounds*	*1,000 lbs.*	*1,000 lbs.*	*1,000 lbs.*	*Lbs. per sq. in.*		
27														Side cut, large old-growth fir type, top portion of first 40-foot log (compression failure in timber prior to test).
29	11.84	11.90	24	0	31.5	.411	1,724	3,275	337.2	326.8	315.3	2,285	S	Side cut, large yellow fir type, top portion of first 40-foot log, clear.
31	11.88	11.92	23	11 7/16	31.4	.435	1,691	3,250	336.0	318.8	303.0	2,195	S	Side cut, large yellow fir type, butt cut, clear.
33	11.64	11.88	24	1/16	28.1	.437	1,887	3,400	350.0	315.9	321.8	2,330	S	Boxed heart, red fir type, one end split, many knots (½ to 2 inches) on all faces.
35	11.84	11.82	24	5/8	30.0	.471	1,976	3,725	382.0	357.7	349.0	2,530	S	Do.
37	11.90	11.92	24	5/16	34.5	.481	945	1,825	187.5	[3] 198.7	189.0	1,370	Cull.	Side cut, large yellow fir type, top portion of first 40-foot log, many knots (½ to 5½ inches) on all faces.
39	11.93	11.77	23	11¾	30.9	.413	1,119	2,150	221.7	207.6	197.8	1,430	Cull.	Side cut, large yellow fir type, top portion of first 40-foot log, many knots (1 to 4¾ inches) on all faces.
41	11.74	11.70	24	¼	44.2	.418	1,908	3,475	357.0	372.1	375.2	2,720	S	Boxed heart, small yellow fir type, butt cut, clear.
42	11.74	11.70	23	11⅞	31.5	.471	2,157	3,925	404.5	399.5	402.0	2,930	S	Boxed heart, small yellow fir type, top cut, many small knots (½ to 1 inch) on all faces.
43	11.75	11.73	23	11⅞	30.0	.469	1,804	3,300	340.0	344.7	344.7	2,498	S	Boxed heart, small yellow fir type, butt cut, a few small knots (¼ to ½ inch) on three faces.
44	11.57	11.65	23	11 15/16	30.6	.456	1,770	3,070	316.1	[3] 335.0	353.5	2,560	S	Boxed heart, small yellow fir type, top cut, many knots (¾ to 1½ inches) on all faces.
45	11.56	11.62	24	0	31.3	.446	1,652	2,850	293.6	[3] 311.0	330.3	2,392	S	Boxed heart, small yellow fir type, butt cut, many knots (¾ to 1 inch) on three faces.
46	11.52	11.54	24	0	31.0	.442	1,651	2,800	288.2	304.4	329.0	2,385	S	Boxed heart, small yellow fir type, butt cut, many knots (½ to 1½ inches) on three faces.
47	11.71	11.62	24	0	30.8	.390	1,402	2,520	259.5	272.2	278.0	2,015	S	Boxed heart, large old-growth fir type, top portion of first 40-foot log, many knots (½ to 2 inches) on all faces.
48	11.72	11.60	23	11⅞	31.0	.405	1,587	2,850	293.7	311.7	317.8	2,300	S	Boxed heart, large old-growth fir type, top portion of first 40-foot log, many knots (½ to 1½ inches) on two faces.

49	11.59	11.66	24	⅛	33.4	.371	1,524	2,660	273.7	253.4	266.8	1,930	S	Boxed heart, large old-growth fir type, top portion of first 40-foot log, many knots (¾ to 2½ inches) on all faces.
50	11.61	11.54	24	⅜	37.0	.448	1,438	2,500	256.8	220.6	233.4	1,690	S	Side cut, large old-growth fir type, top portion of first 40-foot log, many knots (¾ to 4 inches) on all faces.
51	11.69	11.72	24	0	33.9	.397	1,192	2,145	221.0	219.3	223.2	1,617	Cull.	Side cut, large old-growth fir type, top portion of first 40-foot log, a few large knots on each of the four faces.
52	11.63	11.57	23	11⅞	33.6	.428	1,286	2,250	231.8	228.4	239.2	1,735	C	Side cut, large old-growth fir type, top portion of first 40-foot log, a few large knots on three faces.
53	11.54	11.55	24	0	35.0	.462	1,730	2,950	304.0	285.3	306.6	2,220	S	Side cut, large old-growth fir type, butt cut, clear.
54	11.60	11.68	24	¼	36.0	.484	1,741	3,050	313.4	316.0	331.0	2,400	S	Do.
55	11.54	11.59	24	⅛	43.8	.407	1,443	2,470	254.0	252.5	270.5	1,960	S	Side cut, large yellow fir type, butt cut, clear, cross grained.
56	11.56	11.53	24	0	31.4	.490	1,915	3,280	337.8	348.0	372.5	2,700	S	Side cut, large yellow fir type, upper cut, clear.
57	11.69	11.70	23	11⅞	30.6	.389	1,363	2,450	252.4	246.4	251.2	1,820	C	Side cut, large yellow fir type, butt cut, many knots (¾ to 4 inches) on all faces.
58	11.52	11.50	23	10¾	30.4	.427	1,099	1,860	193.2	198.6	213.6	1,548	Cull.	Boxed heart, large yellow fir type, top cut, many knots (¾ to 5 inches) on all faces.
59	11.64	11.68	24	⅛	28.5	.478	2,400	4,250	437.0	426.4	442.3	3,210	S	Boxed heart, small red fir type, butt cut, clear.
60	11.58	11.67	24	⅛	27.6	.459	1,951	3,400	350.0	[3] 371.0	390.8	2,830	S	Boxed heart, small red fir type, top portion of first 48-foot log, many knots (¾ to 1½ inches).

[3] Actual test load reduced to 106 per cent of expected Euler load.

TABLE 3.—*Tests of long columns of southern yellow pine in an air-dry condition*

Column No.	Dimensions: Depth	Dimensions: Breadth	Dimensions: Length		Moisture content	Specific gravity, oven-dry, based on volume when tested	Modulus of elasticity [1]	Stiffness; test span 200 inches, load at 0.2-inch deflection	Maximum expected column load based on stiffness test and determined by the Euler formula	Actual maximum column test load	Values adjusted to an arbitrary standard dimension of 11½ by 11½ inches by 24 feet: Adjusted test load	Values adjusted: $\frac{P}{A}$	Grade [2]	General description of columns tested
	Inches	*Inches*	*Ft.*	*In.*	*Per cent*		*1,000 lbs. per sq. in.*	*Pounds*	*1,000 lbs.*	*1,000 lbs.*	*1,000 lbs.*	*Lbs. per sq. in.*		
11	11.50	11.53	23	11 7/8	17.0	0.512	1,616	2,725	281.0	263.6	262.5	1,985	S	A few knots (¾ to 1½ inches) on all faces.
12	11.56	11.60	23	11 1/2	17.5	.588	1,930	3,325	343.5	319.5	311.0	2,350	S	Several knots (1 to 3 inches).
[3] 13	11.47	11.45	23	11 1/4	18.2	.621	2,031	3,375	349.2	332.6	335.0	2,530	S	Clear, considerable compression wood, badly twisted.
[3] 14	11.30	11.28	24	0	16.1	.464	1,438	2,250	231.7	227.7	244.8	1,850	C	Many knots up to 3 inches in size.
[3] 15	11.56	11.59	23	11 3/4	18.1	.566	1,845	3,175	327.3	305.5	298.6	2,250	S	A few small knots.
16	11.32	11.69	23	11 1/4	18.6	.630	1,828	2,980	308.3	282.7	290.0	2,180	S	Many small knots.
[3] 17	11.59	11.53	23	10 7/8	17.8	.508	1,892	3,262	338.5	324.9	313.8	2,370	S	One large knot at middle of timber.
18	11.68	11.63	23	11 3/8	17.5	.456	932	1,662	171.8	161.1	151.5	1,115	Cull.	Many knots (1 to 6 inches).
[3] 19	11.30	11.43	24	0	18.0	.548	1,949	3,090	318.0	287.8	305.0	2,305	S	Clear.
[3] 20	11.52	11.53	23	11 9/16	16.5	.448	1,268	2,150	222.0	197.2	195.0	1,475	C	Many knots (1 to 3 inches).
31	11.66	11.66	24	0	17.7	.502	1,637	2,910	299.6	265.9	251.3	1,900	S	A few knots (¾ to 3 inches).
32	11.65	11.46	24	1/8	19.8	.609	1,851	3,225	331.8	337.4	326.3	2,468	S	A few small knots (¾ to 1 inch).
33	11.53	11.49	23	11 3/4	18.6	.516	1,742	2,950	304.2	289.6	287.2	2,170	S	Many knots (1 to 3 inches), cut from crooked log.
34	11.50	11.63	23	11 1/2	18.1	.528	1,837	3,125	323.0	313.9	309.3	2,340	S	Clear.
[3] 35	11.58	11.36	24	1/8	16.0	.476	1,708	2,900	298.2	282.2	280.0	2,118	S	Practically clear.
36	11.40	11.14	24	3/8	18.1	.502	1,731	2,820	289.5	252.6	261.4	1,976	C	Many knots (1½ to 4 inches).
[3] 37	11.48	11.54	24	1/8	18.1	.584	2,055	3,450	355.0	334.0	334.5	2,530	S	A few knots (¾ to 2 inches).
38	11.57	11.52	24	0	20.0	.618	1,574	2,700	278.0	277.9	272.4	2,060	C	A few knots (1½ to 4 inches).
39	11.54	11.66	24	0	17.5	.562	1,698	2,925	301.0	297.7	291.0	2,200	S	Many knots (1 to 2½ inches).
[3] 40	11.62	11.49	24	0	18.5	.584	2,050	3,550	365.4	338.5	328.5	2,480	S	Several small knots (½ to 1 inch).
51	11.71	11.71	24	0	20.0	.535	1,631	2,950	303.8	306.1	284.7	2,150	S	A few large knots (1½ to 3 inches).
52	11.45	11.56	23	11 3/4	19.1	.512	1,380	2,305	237.8	223.0	221.5	1,697	S	Many large knots (1½ to 3 inches).
53	11.61	11.56	23	11 3/4	19.1	.536	1,868	3,250	335.2	302.6	292.0	2,208	S	Practically clear, some shake.
54	11.47	11.57	23	11 3/4	19.0	.554	1,995	3,352	345.8	322.1	322.5	2,440	S	Clear.
55	11.62	11.58	23	11 7/8	19.7	.538	1,669	2,918	300.7	271.0	260.5	1,970	Cull.	Two large knots (3 to 5 inches).
56	11.56	11.40	23	11 3/4	19.6	.570	2,230	3,775	388.5	375.1	372.5	2,815	S	Clear.
57	11.64	11.50	23	11 3/4	19.7	.483	1,344	2,342	241.6	233.1	224.7	1,697	S	Several knots (¾ to 1½ inches).
58	11.68	11.64	23	11 5/8	21.6	.513	1,600	2,855	294.8	285.7	269.0	2,035	S	Several knots (2 to 2¼ inches).
59	11.66	11.52	23	11 5/8	19.0	.578	1,727	3,031	313.0	298.5	285.0	2,155	S	A few small knots (¾ inch).
60	11.56	11.65	23	11 7/8	20.0	.577	1,926	3,335	343.8	321.3	312.0	2,360	S	Clear.
71	11.66	11.42	23	11 3/4	19.2	.535	1,847	3,214	331.4	327.5	316.0	2,388	S	Several knots (¾ to 2½ inches).
72	11.58	11.55	23	11 3/4	--------	.552	2,002	3,456	356.3	349.2	340.0	2,570	S	Clear.

73	11.59	11.63	24	⅛	18.4	.577	1,464	2,518	262.0	240.8	233.2	1,764	S	Many knots (¾ to 2½ inches).
74	11.69	11.56	23	11½	19.3	.556	1,887	3,350	346.3	346.6	327.2	2,474	S	Several knots (1¼ to 2 inches).
75	11.67	11.48	23	11⅞	19.1	.582	2,103	3,690	380.3	352.7	338.0	2,555	S	A few small knots (1 inch).
76	11.68	11.58	23	11⅞	18.7	.530	1,491	2,648	273.6	256.0	242.3	1,833	S	Many knots (¾ to 2 inches).
77	11.32	11.53	23	11⅞	19.5	.543	1,758	2,828	291.3	258.0	269.3	2,038	S	Many knots (1 to 3 inches).
78	11.62	11.68	23	11¾	20.0	.582	2,190	4,650	398.5	402.5	383.0	2,895	S	A few knots (1¼ inches).
79	11.58	11.59	23	11¾	--------	.589	1,945	3,369	347.4	314.0	304.7	2,300	S	Practically clear.
80	11.58	11.72	23	11¾	17.4	.557	1,963	3,435	354.0	343.9	330.0	2,494	S	Several knots (1½ inches).

[1] A factor of 4 per cent has been included in the formula for modulus of elasticity to take care of the difference in shear distortion over a 200-inch span as against a 288-inch span making it read $E=\frac{1.04PL^3}{48DI}$

[2] American Society for Testing Materials standard grades: S=Select grade; C=Common grade. (See Amer. Soc. Testing Materials Standards Vol. 27, p. 581.)

[3] Southern yellow pine other than longleaf.

TABLE 4.—*Tests of long columns of Douglas fir in an air-dry condition*

Column No.	Dimensions				Moisture content	Specific gravity, oven-dry, based on volume when tested	Modulus of elasticity [1]	Stiffness; test span 200 inches, load at 0.2-inch deflection	Maximum expected column load based on stiffness test and determined by the Euler formula	Actual maximum column test load	Values adjusted to an arbitrary standard dimension of 11½ by 11½ inches by 24 feet		Grade [2]	General description of columns tested
	Depth	Breadth	Length								Adjusted test load	$\frac{P}{A}$		
	Inches	*Inches*	*Ft.*	*In.*	*Per cent*		*1,000 lbs. per sq. in.*	*Pounds*	*1,000 lbs.*	*1,000 lbs.*	*1,000 lbs.*	*Lbs. per sq. in.*		
2	11.49	11.54	21	0	18.1	0.452	2,063	3,475	358.0	345.9	315.5	2,610	S	Boxed heart, small yellow fir type, top cut, many knots (¾ inch) on one face.
7	11.50	11.38	24	0	18.3	.356	2,363	3,938	405.5	369.8	373.8	2,830	S	Boxed heart, small yellow fir type, butt cut, many knots (¾ to 1½ inches) on all faces.
8	11.67	11.46	23	11¾	18.5	.377	1,462	2,562	264.2	255.0	244.8	1,850	S	Boxed heart, small yellow fir type, top cut, many knots (½ to 1¼ inches) on all faces.
9	11.48	11.51	24	0	17.5	.406	1,825	3,062	315.4	299.2	300.0	2,270	S	Boxed heart, small yellow fir type, butt cut, many knots (¾ to 3 inches) on two faces.
10	11.57	11.56	23	11¾	17.7	.410	1,758	3,025	312.0	288.6	281.6	2,130	S	Boxed heart, small yellow fir type, top cut, many knots (1 to 3 inches) on two faces.
11	11.59	11.56	23	1115/16	18.9	.445	1,787	3,094	319.0	300.4	292.0	2,210	S	Boxed heart, small yellow fir type, butt cut, many knots (1 to 2½ inches) on three faces.
14	11.54	11.52	23	11¾	19.7	.492	1,870	3,181	328.0	313.8	310.0	2,340	S	Side cut, large old-growth fir type, top portion of first 40-foot log, clear.
16	11.14	11.62	21	1/16	18.4	.436	1,891	3,162	325.5	310.0	312.1	2,360	S	Do.
18	11.50	11.56	23	11⅞	19.7	.413	1,819	3,075	317.0	299.0	297.2	2,250	S	Side cut, large old-growth fir type, many small knots, one knot 1½ inches in size, near top end.
20	11.59	11.58	24	0	17.1	.492	2,050	3,556	366.1	356.0	345.3	2,610	S	Side cut, large old-growth fir type, a few knots (1 to 1½ inches) near top end.
22	11.50	11.62	24	¼	19.0	.421	1,589	2,700	277.5	259.7	257.8	1,950	S	Side cut, large old-growth fir type, a few knots (1 to 2 inches) near top end.
24	11.60	11.58	23	11 13/16	18.9	.479	1,748	3,038	313.3	275.0	265.8	2,010	S	Side cut, large old-growth fir type, a few knots (1 to 3 inches) on two faces near top end.
26	11.58	11.61	23	11⅜	18.2	.418	1,400	2,586	267.5	250.6	242.2	1,830	S	Boxed heart, large old-growth fir type, many knots (1 to 3 inches) near top end.
28	11.66	11.58	23	11⅞	18.1	.432	1,412	2,492	257.0	231.8	220.6	1,670	C	Side cut, large old-growth fir type, many knots (1 to 4 inches) near top end.
30	11.83	11.68	23	11⅝	18.1	.407	1,502	2,794	288.7	273.6	246.6	1,865	S	Side cut, large yellow fir type, top portion of first 48-foot log, clear.
32	11.59	11.35	23	11 11/16	19.0	.447	1,650	2,805	289.6	282.3	278.8	2,110	S	Side cut, large yellow fir type, butt cut, clear.
34	11.53	11.63	24	0	18.5	.419	1,995	3,419	352.0	319.6	313.0	2,370	S	Boxed heart, medium sized red fir type, a few small knots.
36	11.42	11.50	23	4	18.5	.431	1,856	3,060	333.8	312.8	302.0	2,280	S	Boxed heart, medium-sized red fir type, many small knots.
38	11.54	11.52	24	11¾	19.0	.460	1,115	1,900	181.0	183.5	196.4	1,485	Cull.	Side cut, large yellow fir type, top portion of first 48-foot log, many knots (½ to 6 inches) on all faces.

40	11.53	11.52	24	1/8	18.9	.442	1,575	2,674	275.2	256.4	254.4	1,925	Cull.	Side cut, large yellow fir type, top portion of first 48-foot log, many knots (1/2 to 5 inches) on all faces.
61	11.50	11.57	23	11 7/8	17.0	.492	2,282	3,862	398.0	357.1	354.6	2,682	S	Boxed heart, small yellow fir type, butt cut, many small knots (1/2 to 3/4 inch) on three faces.
62	11.60	11.50	23	11 13/16	18.0	.456	2,082	3,594	370.8	361.7	352.0	2,685	S	Boxed heart, small yellow fir type, top cut, many small knots (1/2 to 3/4 inch) on three faces.
63	11.54	11.52	23	11 11/16	17.5	.471	1,932	3,288	339.0	308.8	304.2	2,302	S	Boxed heart, small yellow fir type, butt cut, many knots (3/4 to 1 1/4 inches) on two faces.
64	11.46	11.42	24	0	18.0	.500	2,344	3,875	399.0	391.2	398.5	3,015	S	Boxed heart, small yellow fir type, top cut, many small knots (1/2 to 1 inch) on three faces.
65	11.51	11.52	23	11 13/16	17.6	.471	2,060	3,480	359.0	357.3	355.2	2,690	S	Boxed heart, small yellow fir type, butt cut, many knots (3/4 to 2 inches) on one face.
66	11.51	11.55	24	0	17.5	.483	2,229	3,775	389.0	380.9	378.0	2,860	S	Boxed heart, small yellow fir type, butt cut, many knots (1/2 to 1 1/2 inches) on two faces.
67	11.52	11.42	23	11 13/16	17.7	.469	2,161	3,625	373.7	369.2	369.4	2,792	S	Boxed heart, large old-growth fir type, top portion of first 40-foot log, many knots (1/2 to 1 1/2 inches) on three faces.
68	11.58	11.44	24	3/16	18.0	.426	1 765	3,014	309.8	292.7	288.8	2,180	S	Boxed heart, large old-growth fir type, top portion of first 40-foot log, many knots (1/2 to 1 1/4 inches) on all faces.
69	11.46	11.44	23	11 13/16	18.0	.434	1,840	3,050	314.6	292.2	296.6	2,240	S	Boxed heart, large old-growth fir type, top portion of first 40-foot log, many knots (1/2 to 1 1/2 inches) on all faces.
70	11.71	11.58	24	3/32	17.9	.434	1,573	2,814	289.6	262.8	247.3	1,870	S	Side cut, large old-growth fir type, top portion of first 40-foot log, a few knots (1 to 2 inches) on all faces.
71	11.78	11.59	23	11 7/8	18.7	.487	1,232	2,244	231.4	205.2	189.2	1,432	Cull.	Side cut, large old-growth fir type, top portion of first 40-foot log, many knots (7/8 to 3 inches) on all faces.
72	11.65	11.55	23	11	17.7	.452	1,630	2,862	296.9	270.0	257.0	1,945	C	Side cut, large old-growth fir type, top portion of first 40-foot log, many knots.
73	11.54	11.46	24	0	16.8	.364	1,437	2,435	250.8	239.0	237.3	1,795	S	Side cut, large old-growth fir type, butt cut, clear.
74	11.60	11.59	23	11 5/8	19.2	.508	2,183	3,800	392.8	385.1	371.0	2,810	S	Do.
75	11.50	11.61	23	11 13/16	18.4	.420	1,538	2,615	269.8	257.4	354.8	1,928	S	Side cut, large yellow fir type, butt cut, clear.
76	11.52	11.49	23	11 7/8	18.4	.508	2,131	3,600	371.0	362.7	360.4	2,730	S	Side cut, large yellow fir type, top cut, clear.
77	11.61	11.48	23	11 9/16	17.0	.404	1,612	2,788	288.0	275.5	267.3	2,025	C	Side cut, large yellow fir type, butt cut, many large knots.
78	11.56	11.57	23	10	17.2	.439	1,190	2,048	214.0	190.6	183.8	1,390	Cull.	Side cut, large yellow fir type, top cut, many large knots.
79	11.43	11.55	23	11 13/16	18.4	.525	2,408	3,994	412.0	389.1	394.0	2,980	S	Boxed heart, small red fir type, top cut, many knots (3/8 to 1 1/4 inches).
80	11.57	11.39	24	1/2	18.5	.498	2,173	3,688	378.4	364.7	362.8	2,740	S	Boxed heart, small red fir type, butt cut, many knots (1/4 to 1 1/2 inches).

[1] A factor of 4 per cent has been included in the formula for modulus of elasticity to take care of the difference in shear distortion over a 200-inch span as against a 288-inch span, making it read $E=\frac{1.01PL^3}{48DI}$.

[2] American Society for Testing Materials standard grades: S=Select grade; C=Common grade. (See Amer. Soc. Testing Materials Standards Vol. 27, p. 581.)

The timbers were surfaced on a jointer and therefore varied slightly in size. For this reason the strength values were adjusted to arbitrary standard specimen dimensions of 11¾ by 11¾ inches by 24 feet for the green timbers, and 11½ by 11½ inches by 24 feet for the air-seasoned timbers. These values are given in the tables under the heading "Values adjusted."

The tables of results for the green timbers show that the columns sometimes sustained loads greater than their calculated Euler loads. Such columns (if the stiffness calculated from the bending tests is considered as the true stiffness of the timber) are in unstable equilibrium and the excess loads have no significance. Because of the relatively low load to which they were subjected in the bending test, there is a discrepancy between the true stiffness of the columns and that calculated from the bending tests. The green columns were not considered in unstable equilibrium unless the test load exceeded the expected load by more than 6 per cent in which event the test load was reduced to 106 per cent of the expected load. It may be seen in Table 5 that such reductions lowered the average of the calculated loads to about 98 per cent of the average Euler loads. To avoid unstable equilibrium in testing the air-dry 24-foot columns, they were set with an eccentricity of 0.07 inch; this eccentricity would cause a slight reduction in load which as a rule can not be evaluated absolutely. The test results given in Table 5 indicate that the reduction in load of the air-seasoned columns because of eccentric loading is between 2 and 3 per cent. The values for the air-seasoned timbers in which the test load exceeded the Euler load were considered correct because the slight eccentricity used in loading these columns prevented a condition of unstable equilibrium.

TABLE 5.—*Relation of test load to Euler load for 24-foot columns*

Species of wood	Seasoning condition	Average adjusted Euler load	Average adjusted test load [1]	Ratio of test load to Euler load
		Pounds	*Pounds*	*Per cent*
Southern yellow pine	Green	298, 200	291, 240	97. 8
Do	Air-dry	305, 700	299, 500	97. 9
Douglas fir	Green	311, 500	305, 025	97. 9
Do	Air-dry	314, 600	303, 500	96. 4
Average	Green			97. 85
Do	Air-dry			97. 15

[1] Test values were adjusted for variation of columns in cross section and in length. Cross section for green columns was adjusted to 11¾ by 11¾ inches and that of the air-dry to 11½ by 11½ inches—adjusted length was 24 feet for both. The values for air-dry material were further adjusted to a basis of 18 per cent moisture content.

The maximum and minimum strength values for southern yellow pine columns were obtained with longleaf pine. The difference between the strength of the longleaf pine and the southern pine not longleaf was so slight that the omission of the southern yellow pine not longleaf from the averages would have raised the green values by less than 3 per cent and would have lowered the air-seasoned values by less than 1 per cent. In summarizing the results of these tests therefore the pine columns are considered collectively and are called by the general name southern yellow pine.

The maximum, minimum, and average values for the long columns of both Douglas fir and southern yellow pine, for the two conditions of seasoning and for both winter and summer cutting, are given in Table 6. The figures show an advantage in strength for winter-cut material. This advantage may in part be attributed to the fact that these timbers were tested in colder weather, which would cause them to support somewhat greater loads than in warm weather, but after due consideration of the effects of temperature and any slight difference in moisture content and specific gravity of the timbers the advantage shown for the winter-cut timbers is still greater than that normally attributed to accident.

TABLE 6.—*Summary of strength values for Douglas fir and southern yellow pine 24-foot columns*

Species of wood	Season when cut	Season when tested	Condition when tested	Adjusted column strength values [1]		
				Maximum	Minimum	Average
				Pounds	*Pounds*	*Pounds*
Southern yellow pine	Summer	Summer	Green	386,600	196,400	282,430
Do	Winter	Winter	do	406,800	177,000	300,050
Do		Summer and winter.	do			291,240
Do	Summer	Summer	Air-dry	355,000	149,600	281,500
Do	Winter	Winter	do	425,000	236,500	317,500
Do		Summer and winter.	do			299,500
Douglas fir	Summer	Summer	Green	383,000	189,000	296,021
Do	Winter	Winter	do	442,300	213.600	313,580
Do		Summer and winter.	do			305,025
Do	Summer	Summer	Air-dry	381,000	206,000	292,000
Do	Winter	Winter	do	401,000	176,000	309,500
Do		Summer and winter.	do			303,500

[1] Test values were adjusted for variation of columns in cross section and in length. Cross section for green columns was adjusted to 11¾ by 11¾ inches and that of the air-dry 11½ by 11½ inches—adjusted length 24 feet for both. The values for air-dry material were further adjusted to a basis of 18 per cent moisture content.

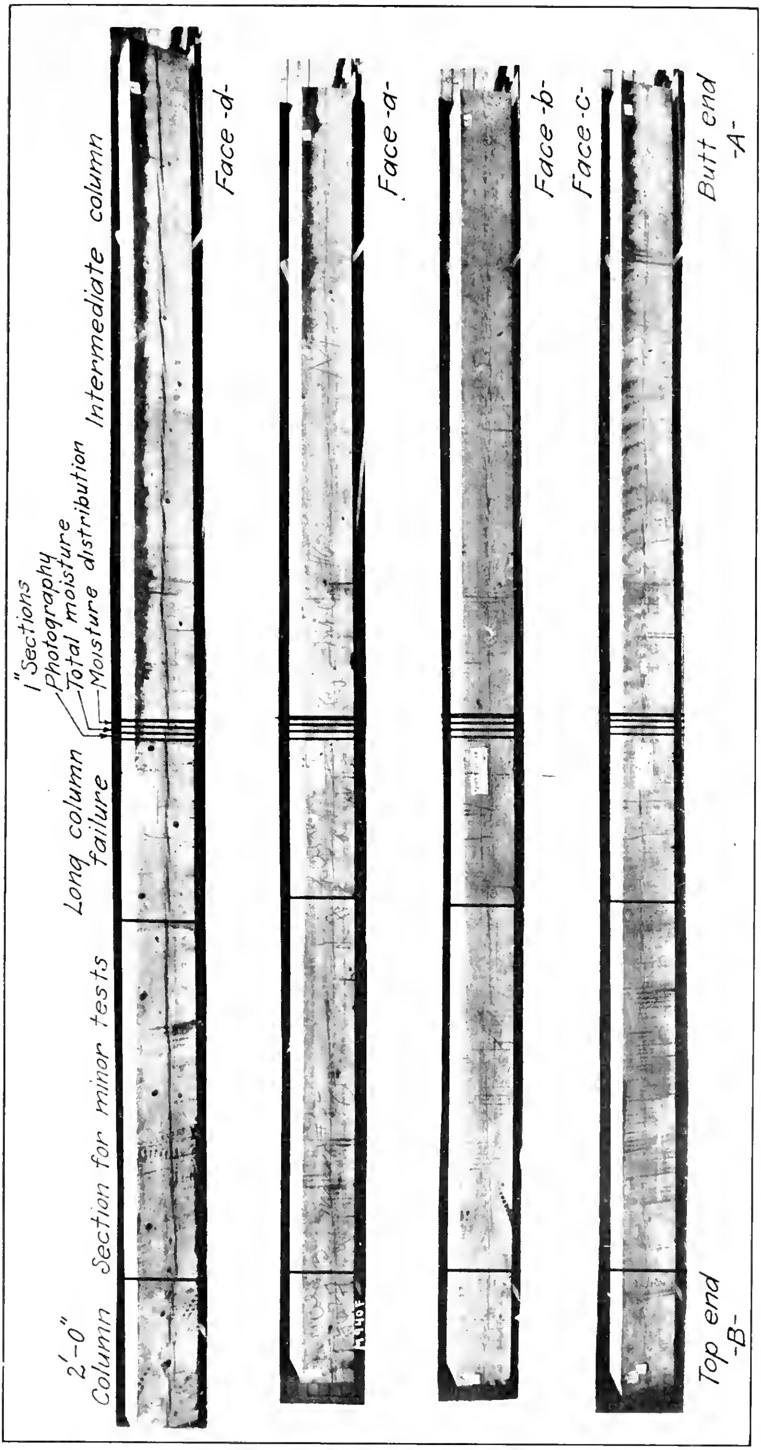
The tests show further that the maximum load which a long column will support is dependent upon its stiffness. The one-fourth inch reduction in cross-sectional dimensions of the air-seasoned timbers below that of the green timbers (about one-eighth of which results from shrinkage in seasoning from the green condition and the other one-eighth from surfacing) reduced the stiffness of the columns by an amount practically equal to the normal increase in stiffness of the wood caused by seasoning. Consequently the green and air-dry columns carried practically the same loads.

The Douglas fir long columns averaged 3 to 4 per cent higher in stiffness than the southern yellow pine and therefore withstood correspondingly higher loads. This small difference in stiffness, however, is not sufficient to justify the conclusion that Douglas fir is better as a long column than southern pine, regardless of the care exercised in selection, since the normal variation in strength of wood is such that a difference greater than the above would be expected between two such groups of timbers of the same species, either all Douglas fir or all southern pine or any other wood used for structural purposes.

The specific-gravity values of the material tested as compared to those of thousands of specimens of both species used in other tests at the Forest Products Laboratory show that in the selection of the long columns the range in density for each species was well covered.

INTERMEDIATE AND 2-FOOT COLUMN TESTS

Table 7 contains the data for the intermediate length and the 2-foot columns tested in the green and air-seasoned condition, together with the maximum compressive stress values from tests of standard 2 by 2 inch clear specimens. The table shows that the strength of the intermediate columns differed but little from that of the 2-foot columns, although some of the intermediate columns were 13 feet long. The results show that even with pin-ended bearings, which would be expected to always give lower results than square-ended bearings, and with good bearing surfaces, the length of these columns up to 11 times their least dimension had little effect on the strength.



The relative positions of intermediate and 2-foot columns, and the sections from which minor test specimens were cut

M925F

A long column mounted upon the special roller bearings preparatory to test in the Forest Products Laboratory 1,000,000-pound timber-testing machine

TABLE 7.—*Tests of nominal 12 by 12 inch columns of intermediate and 2-foot lengths and of clear minor specimens 2 by 2 by 8 inches*[1]

SOUTHERN YELLOW PINE

Green

Column No.	Intermediate: Grade[2]	Intermediate: Moisture	Intermediate: Length	Intermediate: P/A	Two-foot columns: Grade[2]	Two-foot columns: Moisture	Two-foot columns: P/A	Minor specimens: Moisture	Minor specimens: P/A
		Per cent	*Feet*	*Lbs. per sq. in.*		*Per cent*	*Lbs. per sq. in.*	*Per cent*	*Lbs. per sq. in.*
1	S	50.3	11.96	2,820	S	57.0	3,000	47.0	2,970
2	S	27.8	10.77	4,100				25.6	4,410
3	C	30.8	13.00	3,425				28.7	4,233
4	C	44.8	12.00	2,960	C	39.2	2,910	45.3	3,152
5	C	29.8	11.50	3,600	C	23.7	4,240	26.7	4,050
6	S	32.8	10.06	3,790	S	31.3	3,890	29.7	3,998
7	S	27.3	12.00	4,930	S	26.5	4,580	26.5	4,663
8	S	37.5	9.50	3,510	S	34.3	3,380	30.6	3,120
9	S	30.6	13.00	5,010	S	31.2	5,360	34.6	4,910
10	S	27.9	11.33	4,890	S	30.2	4,840	33.2	4,478
21	C	31.5	10.33	3,530	S	26.8	4,000	24.9	4,177
22	S	29.1	10.00	4,345	S	27.1	4,800	26.0	4,178
23	S	28.2	9.65	4,450	S	26.1	4,460	26.5	4,022
24	S	36.4	10.68	3,240	S	36.1	3,590	29.6	3,261
25	S	41.3	10.08	3,480	S	36.6	3,990	36.2	4,262
26	S	28.8	11.15	4,550	S	26.5	4,470	26.5	4,702
27	C	40.5	10.82	2,930	C	59.0	3,540	49.7	2,981
28	S	47.0	11.46	3,870	S	50.6	3,430	31.0	3,165
29	C	37.9	10.33	3,090	C	34.4	3,330	28.7	3,409
30	S	26.6	9.83	3,770	S	27.0	4,500	26.7	3,780
41	S	34.5	9.74	3,070	S	28.5	4,150	26.1	3,780
42	S	31.3	7.68	3,560	S	32.4	3,620	47.8	3,210
43	S	36.3	9.58	4,300	S	35.0		36.3	4,370
44	S	29.9	10.42	4,390	S	30.4	4,716	35.2	4,520
45	S	33.4	9.04	3,510	S	34.0	3,340	29.9	3,870
46	S	35.6	10.73	4,120	S	33.5	4,450	32.4	4,450
47	S	31.5	9.68	4,640	S	30.0	4,900	29.3	4,900
48	C	26.7	9.65	3,290	C	27.6	3,840	27.8	4,380
49	S	31.4	9.97		S	30.4	3,740	30.9	3,550
50	S	39.4	9.37	4,550	S	30.7	5,420	40.2	4,500
61	C	29.4	9.54	3,030	S	29.5	3,460	27.4	2,290

Air-dry

Column No.	Intermediate: Grade[2]	Intermediate: Moisture	Intermediate: Length	Intermediate: P/A	Two-foot columns: Grade[2]	Two-foot columns: Moisture	Two-foot columns: P/A	Minor specimens: Moisture	Minor specimens: P/A
		Per cent	*Feet*	*Lbs. per sq. in.*		*Per cent*	*Lbs. per sq. in.*	*Per cent*	*Lbs. per sq. in.*
11	S	17.4	7.67	4,760	S	16.5	5,430	15.9	4,913
12	S	18.3	7.46	5,810	S	18.0	5,330	16.8	5,520
13	S	18.6	9.00	5,170	S	16.4	5,620	17.1	6,155
14	S	15.8	9.00	4,015	S	14.3	4,010	15.1	4,710
15	S	16.8	8.79	5,040	S	16.0	5,565	16.1	5,245
16	S	17.8	9.29	4,690	S	19.3	5,300	17.3	5,135
17	S	18.2	8.50	4,735	S	16.6	4,850	17.4	5,640
18	S	16.8	9.15	3,560	C	16.4	3,060	15.2	3,850
19	S	17.5	9.00	4,650	S	19.0	4,910	17.6	5,695
20	C	17.0	10.21	3,130	S	14.2	4,560	16.4	4,680
31	S	18.3	10.58	4,600		16.2		15.3	5,603
32	S	20.5	8.90	5,340	S	16.9	6,025	19.2	5,953
33	S	18.5	7.00	5,100	S	18.4	5,540	16.8	5,858
34	S	18.6	10.00	5,100	S	16.0	5,550	17.3	5,943
35	S	16.6	6.92	4,700	S	16.4	4,920	16.8	5,695
36	S	18.5	11.00	4,280	S	17.0	4,540	15.4	5,092
37	S	18.1	9.00	5,350	S	17.2	5,960	15.8	6,932
38	S	19.6	12.00	5,100	S	17.2	5,620	16.4	5,787
39	S	18.5	12.00	4,870	S	16.5	5,260	16.0	5,865
40	S	18.1	9.50	6,040	S	18.4	6,340	16.2	7,290
51	S	20.2	9.00	5,220	S	17.3	4,440	15.6	5,455
52	S	18.7	10.83	4,210	S	17.5	4,050	15.5	5,362
53	S	19.0	9.50	5,450	S	17.8	5,200	16.0	5,969
54	S	19.0	9.29	6,045	S	17.6	5,330	14.5	6,322
55	S	19.5	11.75	4,900	C	18.4	4,530	14.2	5,853
56	S	19.0	12.00	5,600	S	18.2	5,880	15.5	6,983
57	S	19.6	10.27	3,250	S	19.2	3,800	13.0	5,685
58	S	21.4	8.67	5,060	S	18.6	4,330	15.7	5,815
59	S	19.5	7.75	5,250	S	19.9	6,000	14.7	6,715
60	S	15.0	10.10	5,315	S	19.1	5,580	14.6	6,530
71	S	18.6	7.67	4,260	S	18.3	5,440	14.5	6,425

[1] The omissions in the table indicate a lack of test material resulting from the type of failures in the 24-foot columns.
[2] S=Select grade; C=Common grade.

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TABLE 7.—*Tests of nominal 12 by 12 inch columns of intermediate and 2-foot lengths and of clear minor specimens 2 by 2 by 8 inches*—Continued

SOUTHERN YELLOW PINE—Continued

Green										Air-dry									
Column No.	Intermediate				Two-foot columns			Minor specimens		Column No.	Intermediate				Two-foot columns			Minor specimens	
	Grade	Moisture	Length	$\frac{P}{A}$	Grade	Moisture	$\frac{P}{A}$	Moisture	$\frac{P}{A}$		Grade	Moisture	Length	$\frac{P}{A}$	Grade	Moisture	$\frac{P}{A}$	Moisture	$\frac{P}{A}$
		Per cent	Feet	Lbs. per sq. in.		Per cent	Lbs. per sq. in.	Per cent	Lbs. per sq. in.			Per cent	Feet	Lbs. per sq. in.		Per cent	Lbs. per sq. in.	Per cent	Lbs. per sq. in.
62	S	30.2	9.92	5,340	S	29.9	5,170	29.7	4,890	72	S	18.6	10.90	5,475	S	18.4	6,100	16.6	6,942
63	C	31.6	9.05	3,160	S	30.6	3,220	33.9	2,790	73	S	18.9	9.42	4,140	S	19.0	3,900	17.7	4,778
64	S	38.0	10.98	3,810	S	39.0	4,070	35.5	3,780	74	S	18.6	9.29	5,950	S	19.1	5,820	14.8	6,755
65	S	34.1	9.79	3,810	S	46.5	4,280	54.2	3,190	75	S	18.8	8.94	5,900	S	16.6	5,950	14.5	7,315
66	S	34.7	11.03	3,720	S	37.0	4,090	33.7	3,750	76	S	19.0	9.54	4,640	S	17.2	5,025	13.2	5,792
67	S	32.9	9.27	3,160	S	34.1	3,200	34.3	3,460	77	S	20.0	7.60	4,770	S	16.6	4,710	14.3	6,075
68	S	32.9	10.25		S	34.0	4,110	33.0	4,230	78	S	19.1	8.19	5,880	S	16.7	6,160	15.4	7,273
69	S	33.6	9.78	3,875			4,010	34.8	3,570	79	S	19.8	9.56	5,650	S	16.1	5,270	14.2	6,147
70	S	28.0	10.12	5,650	S	28.6	5,290	30.7	5,020	80	S	19.6	11.92	5,610	S	14.3	5,555	15.0	6,088

DOUGLAS FIR

Green										Air-dry									
1	S	31.5	10.28	3,739	S	30.9	4,122	27.6	4,070	2	S	17.8	8.54	4,510	S	17.3	5,260	12.9	6,480
3	S	32.0	9.32	3,082	S	31.5	3,163	28.6	3,600	7					S	18.4	5,390	13.5	7,237
4	S	28.7	9.32	3,213	S	28.9	3,275	27.8	3,300	8	S	17.9	7.82	4,055	S	17.9	4,355	13.8	5,197
5	S	31.2			S	31.8	3,185	28.4	3,410	9	S	17.6	7.04	4,040	S	16.3	4,390	11.6	5,990
6	S	29.6			S	30.3	3,022	28.5	3,550	10					S	17.1	4,390	12.6	6,037
12	S		8.36	3,182	S	31.0	3,160	27.5	3,440	11					S	18.3	4,390	13.4	6,307
13	S	34.1	7.81	3,970	S	32.0	3,980	30.1	4,340	14	S	19.5	9.32	5,340	S	19.4	5,462	14.9	6,028
15	S	33.3	8.13	3,310	S	33.8	3,150	31.0	3,100	16	S	18.7	8.73	5,020	S	18.5	5,050	14.3	5,907
17					S	34.4	3,660	31.7	3,470	18	S	18.5	9.59	4,285	S	17.7	4,731	15.5	5,462
19	S	33.5	8.49	3,252	S	33.4	3,382	30.6	3,570	20	S	18.0	7.54	5,540	S	18.3	5,970	16.5	6,327
21								33.7	3,050	22					S	18.0	4,061	14.2	5,637
23	C	32.0	9.42	3,011	C	31.4	3,435	27.4	3,570	24	S	18.0	6.65	4,085	S	17.8	4,270	14.6	4,822
25	S	32.6	8.97	3,640	S	33.4	3,720	33.0	3,680	26					S	18.0	3,888	12.6	5,902
27										28					S	18.1	4,140	10.8	5,819
29	S	32.2	9.19	3,655				29.7	3,510	30					S	18.0	4,120	14.5	4,950
31	S	30.0	10.68	3,825	S	31.4	3,830	29.7	3,880	32	S	19.1	9.37	5,400	S	17.1	5,180	14.0	5,991
33	S	29.4	7.66	3,162	S	28.0	3,745	24.9	4,060	34					S	17.8	5,010	11.6	7,073

35	S	30.5	9.52	3,960	S	29.6	3,990	28.0	4,210
37	S	32.5			C			30.7	3,420
39	Cull.	29.9	6.71	2,220	S	31.4	2,315	28.1	2,900
41	S	30.7	9.78	3,910	S	30.6	4,350	29.6	3,858
42	S	30.4	10.08	4,030	S	30.3	4,280	31.1	4,310
43	S	28.8	9.82	3,770	S	29.6	4,230	29.2	4,340
44	S	29.9	11.92	3,500	S	30.2	3,820	28.9	3,890
45	S	30.9	10.15	3,460	S	30.8	3,820	28.6	4,110
46	S	30.3	9.17	3,630	S	30.1	4,070	28.0	3,940
47	S	30.2	8.08	3,235	S	29.9	3,400	26.2	3,430
48	S	29.9	11.52	3,510	S	30.7	3,450	26.2	3,530
49	S				S	32.5	2,730	27.7	2,956
50	S	36.5	10.50	2,610	S	36.3	3,390	32.7	3,430
51	S	33.2	8.98	2,215	S	33.1	3,110	30.4	2,830
52	C	32.1	13.65	2,490	S	32.2	3,150	30.2	3,170
53	S	34.4	10.63	3,550	S	35.3	3,380	34.3	3,540
54	S	36.0	10.00	3,920	S	35.6	3,670	32.5	3,550
55	S				S	41.7	3,040	36.9	3,020
56	S	30.8	12.09	4,365	S	31.0	4,220	28.6	4,350
57	S	31.5	7.09	2,210	Cull.			27.3	3,280
58	C	29.5	11.15	2,550	S	29.5	2,850	24.7	3,360
59	S	28.8	8.71	4,650	S	28.6	4,330	25.8	4,070
60	S	27.9	8.15	3,945	S	28.0	4,060	25.9	4,900

36					S	18.1	4,405	11.6	6,355
38	Cull.	18.5	8.57	3,189	C	18.2	3,710	15.0	5,014
40					Cull.	18.7	3,445	13.3	5,688
61	S				S	17.4	5,110	15.7	7,035
62	S	19.2	12.08	5,260	S	18.1	5,510	14.1	6,312
63	S				S	18.2	4,400	14.5	5,993
64	S				S	17.7	5,700	15.7	6,627
65	S	19.3	11.53	4,890	S	16.5	5,430	13.9	6,315
66	S	18.5	7.17	5,010	S	18.4	5,840	14.6	6,782
67	S	19.3	5.87	4,830	S	17.2	5,480	13.3	6,903
68	S				S	19.0	3,990	14.2	5,988
69	S				S	17.8	4,840	12.0	6,735
70	S	19.0	8.9	3,510	S	17.9	4,070	16.1	4,935
71								13.9	5,462
72	S	18.5	9.38	3,750	S	18.0	5,220	15.4	5,460
73	S	17.0	9.93	4,130	S	17.7	4,430	14.3	4,642
74	S	19.8	12.02	5,480	S	18.2	5,710	16.7	6,115
75	S	18.9	9.70	4,160	S	19.0	4,200	15.9	4,738
76	S	19.6	10.33	5,920	S	17.7	5,950	15.4	6,287
77					S	18.0	4,320	14.6	5,115
78	C	18.7	7.77	3,200	S	18.8	4,080	13.7	4,662
79	S	19.4	6.82	4,980	S	17.2	6,260	16.8	6,950
80	S				S	18.6	5,210	15.1	6,715

The table also shows somewhat higher ultimate compressive values for the southern yellow pine, both green and air-seasoned, than for the Douglas fir. In southern yellow pine timbers of smaller sizes than 12 by 12 inch cross section, however, a larger percentage of upper cuts would usually be included; such inclusion would lower the average density of the group and consequently the average compressive strength.

KNOTS

A study of the progress of failures in the long columns having knots showed that knots intensify local stresses within a timber and that the fibers adjacent to the knots are the first to be stressed beyond the elastic limit. The long-column tests also show that the effect that knots have on column strength is dependent not only upon their size and location but also upon the length of the timber. If the length is such that the fibers adjacent to the knots are not stressed to the elastic limit before the Euler load is reached, then this type of defect has practically no influence on column strength. The fact that the 24-foot columns of the select grades (Tables 1 to 4) took their full Euler loads indicates the correctness of this assumption. It may also be seen in these tables that the influence of knots on the strength of the long columns as a whole is relatively small and approximately the same for both Douglas fir and southern yellow pine. In fact the test loads for the very knottiest timbers (see values for culls in Tables 3 and 4) are as a rule less than 10 per cent below their calculated Euler loads.

For the short and intermediate columns there were fewer knotty specimens from which to judge the influence of knots on the strength, since these specimens were taken from the long column at some distance from the failure, which usually occurred in the knottiest portion. Only 22 of all the specimens selected were knotty enough to be classed as common grade, and only 3 as cull. Furthermore, on account of the inherent variability in the strength of clear wood and the lack of a proper distribution of the minor specimens throughout the entire timber the results obtained from the tests of minor specimens do not represent exactly the true strength of the clear wood of the timbers. The ratios of expected load to column test load are therefore very erratic. In making deductions as to the effect of knots on the strength of short and intermediate columns, the results of structural timber tests previously made have been used since the present actual column test values check these results. The reduction in column strength of 2-foot and intermediate sections, because of the presence of knots, was found to be approximately proportional to knot size. In other words, the proportional reduction in column strength by a single knot equals the ratio of the projected area [6] of the knot to the cross-sectional area of the column. When the piece contains a number of knots, occurring either singly or in whorls, the effect of all knots within any 6 inches of length is approximately equivalent to the removal of their total projected area from the cross section. Applying this reasoning to the 22 common grade intermediate columns tested, the calculated average loss would be 20 per cent while the actual test results show a reduction in strength of a little

[6] Projected area of a knot in boxed-heart timbers was taken as two-thirds its diameter measured on the surface and multiplied by the length. In side-cut specimens the projected area was calculated as the average diameter of knot times its length on the face measured.

over 16 per cent. In the case of the three culls, the calculated loss is about 27 per cent and the actual loss approximately 29 per cent. This proportionally greater decrease in strength with increase in size of knot in the cull specimens, is in accordance with previous information secured from tests which show that large knots have a somewhat greater weakening effect in proportion to their projected cross-sectional area than smaller ones.

CROSS GRAIN; SPIRAL GRAIN; CHECKS

It was not deemed necessary to make tests to determine the effect of cross grain or spiral grain on the strength of wooden columns, since sufficient tests (*7*) had already been made at the Forest Products Laboratory to show the effect that such defects have on the strength properties of wood. Deductions from previous tests show that in clear wood the stiffness and compressive strength are little affected with slopes of grain less than 1 to 12½. The compressive strength of material free from checks is somewhat less affected than the stiffness.

Tests of structural timbers show that spiral and cross grain further affect the strength because of the normal checking which accompanies seasoning and which invariably follows the grain. While the compressive strength is lowered because of such checking, the stiffness is not materially altered. More severe limitations than are necessary to insure proper strength are usually placed on spiral grain, on account of the twisting which accompanies moisture changes in a timber with such grain.

COLUMN FORMULAS

Prior to the present study a column formula for timber had been derived by the Forest Products Laboratory for use with clear material. The study of wooden columns in structural sizes has shown that this formula applies not only to clear material but also to ordinary structural material when the proper values for modulus of elasticity and crushing strength for the particular species, grade, and condition are inserted (*3*). The conceptions involved in the formula and its application to structural columns are considered in the following discussion.

Certain physical laws are common to all columns. Within the elastic limit of the material, the best interpretation of the law governing the strength of long columns of uniform cross section is that represented by Euler's formula:

$$\frac{P}{A}=u\frac{\pi^2 E}{\left(\frac{L}{r}\right)^2}$$

where P = maximum load on the column (pounds).

A = cross-sectional area of the column (square inches).

E = modulus of elasticity of the material (pounds per square inch).

L = length in inches.

r = radius of gyration of section (inches).

$\frac{L}{r}$ = slenderness ratio of the column.

u = factor depending on end conditions (for pin-ended conditions $u=1$).

From the elastic limit to the point of maximum stress, the curve which represents the load a column will take for different slenderness ratios varies in form with the characteristics of the material (*6*). In wooden columns the curve is smooth as would be anticipated from the nature of any stress-strain curve of a short block of wood in compression. In such a short wooden column the stress-strain curve is a straight line up to the elastic limit. At the elastic limit it breaks away very gradually from the straight line and retains its smooth form out to the point of maximum compressive stress. Any curve which represents the strength values of the column between the elastic limit and point of maximum compressive stress must therefore be a smooth curve tangent to the Euler curve at a $\frac{P}{A}$ equal to the elastic limit stress. A curve of the parabolic type with its vertex, zero $\frac{L}{r}$, at the point of maximum stress, and tangent to the Euler curve at the elastic limit, fulfills these conditions. The general form of this parabola is:

$$\frac{P}{A}=S\left\{1-\left(\frac{S-S'}{S}\right)\left(\frac{\frac{L}{r}}{\frac{L'}{r'}}\right)^{\left(\frac{2S'}{S-S'}\right)}\right\}$$

where S = maximum crushing strength (pounds per square inch).
S' = fiber stress at elastic limit (pounds per square inch).
$\frac{L'}{r'}$ = slenderness ratio of the column when $\frac{P}{A}=S'$ (this may be calculated by substituting the elastic limit stress of the material for $\frac{P}{A}$ in Euler's formula).

For columns of rectangular section this formula may be written:

$$\frac{P}{A}=S\left\{1-\left(\frac{S-S'}{S}\right)\left(\frac{\frac{L}{d}}{\frac{L'}{d'}}\right)^{\left(\frac{2S'}{S-S'}\right)}\right\}$$

where d = least dimension of the section (inches) = $\sqrt{12}\,r$.
$\frac{L}{d}$ = ratio of length to least dimension of a column of rectangular section (also spoken of as slenderness ratio).
$\frac{L'}{d'}$ = slenderness ratio when $\frac{P}{A}$ is equal to S'. In other words it is the $\frac{L}{d}$ ratio at the point of tangency between the parabola and the Euler curve.

If the elastic limit of the column is four-fifths of the maximum crushing strength and if $\frac{L'}{d'}$ is replaced by K_1 this parabolic equation becomes:

$$\frac{P}{A}=S\left\{1-\frac{1}{5}\left(\frac{L}{K_1 d}\right)^8\right\}$$

When S' is two-thirds of the maximum crushing strength of the material and $\frac{L'}{d'}$ is replaced by K the equation takes the form known as the Forest Products Laboratory fourth-power parabolic equation:

$$\frac{P}{A}=S\left\{1-\frac{1}{3}\left(\frac{L}{Kd}\right)^4\right\}$$

K and K_1 are values which depend upon the modulus of elasticity, E, of the species and the fiber stress at the elastic limit. Values for K and K_1 may be found by substituting the assumed value for fiber stress at elastic limit for the species, grade, and condition of use in the Euler formula, the r in the formula being replaced by $\frac{d}{\sqrt{12}}$.

This fourth-power equation requires no greater mathematical skill in its application than the straight-line formulas in common use. Both types require only the solution of relatively simple quadratic equations. It is more convenient, however, to take the required values directly from a table than to solve for them each time they are needed. Table 8 has been prepared for this purpose by substituting the Forest Products Laboratory's recommended safe working stresses in the fourth power and Euler formulas. Values for K and for modulus of elasticity have also been included in the table.

TABLE 8.—*Working stresses for timber conforming to the basic provisions for Select and Common grades of structural material of American lumber standards* [1]

SAFE WORKING STRESSES FOR COLUMNS USED IN A MORE OR LESS CONTINUOUSLY WET OR DAMP LOCATION [2]

Species	Modulus of elasticity [3]	Grades	Value of K	When ratio of length to least dimension $\frac{L}{d}$ is— Short columns	12	14	16	18	20	22	24	26	28	30	35	40	45	50
				Pounds per square inch														
Ash, commercial white	1,500,000	Select	26.2	900	886	876	859	834	798	751	688	609	524	457	336	257	203	164
	1,500,000	Common	29.3	720	714	708	698	686	668	641	612	571	520					
Aspen and largetooth aspen	900,000	Select	28.7	450	446	441	436	427	414	398	377	349	314	274	201	154	122	99
	900,000	Common	32.0	360	358	356	352	348	342	333	322	308	290	269				
Basswood	900,000	Select	28.7	450	446	441	436	427	414	398	377	349	314	274	201	154	122	99
	900,000	Common	32.0	360	358	356	352	348	342	333	322	308	290	269				
Beech	1,600,000	Select	27.0	900	888	878	863	840	810	768	713	642	559	487	358	274	216	175
	1,600,000	Common	30.2	720	714	708	701	690	674	652	624	588	543	486				
Birch, yellow and sweet	1,600,000	Select	27.0	900	888	878	863	840	810	768	713	642	559	487	358	274	216	175
	1,600,000	Common	30.2	720	714	708	701	690	674	652	624	588	543	486				
Cedar, Alaska	1,200,000	Select	27.5	650	642	636	625	611	590	562	526	480	419	365	268	206	162	132
	1,200,000	Common	30.8	520	516	513	507	500	489	475	456	432	402	364				
Cedar, western red	1,000,000	Select	25.1	650	639	629	614	593	564	523	471	405	350	304	224	171	135	110
	1,000,000	Common	28.1	520	514	510	502	491	476	455	428	394	350					
Cedar, northern and southern white	800,000	Select	27.1	450	444	439	432	420	405	384	356	321	280	244	179	137	108	88
	800,000	Common	30.2	360	357	354	351	345	337	326	312	294	271	243				
Cedar, Port Orford	1,200,000	Select	25.6	750	738	728	712	689	657	614	557	487	419	365	268	206	162	132
	1,200,000	Common	28.7	600	594	588	581	569	552	531	502	465						
Chestnut	1,000,000	Select	26.2	600	591	583	572	556	532	500	459	405	350	304	224	171	135	110
	1,000,000	Common	29.2	480	476	472	466	457	445	429	408	381	346					
Cottonwood, eastern and black	900,000	Select	28.7	450	446	441	436	427	414	398	377	349	314	274	201	154	122	99
	900,000	Common	32.0	360	358	356	352	348	342	333	322	308	290	269				
Cypress, southern	1,200,000	Select	24.8	800	786	774	753	726	688	636	566	486	419	365	268	206	162	132
	1,200,000	Common	27.8	640	632	627	617	602	582	556	522	476	419					
Douglas fir (western Washington and Oregon)	1,600,000	Select	26.9	907	895	885	869	847	815	772	716	644	559	487	358	274	216	175
	1,600,000	Common	31.1	680	675	670	664	655	641	624	600	569	531	484				
Douglas fir (dense)	1,600,000	Select	25.8	992	976	963	943	913	872	816	742	649	559	487	358	274	216	175
	1,600,000	Common	28.8	793	785	778	768	753	732	703	666	618	557					
Douglas fir (Rocky Mountain type)	1,200,000	Select	26.5	700	690	682	669	651	625	591	545	487	419	365	268	206	162	132
	1,200,000	Common	29.7	560	555	551	544	535	521	504	480	450	413					
Elm, rock	1,300,000	Select	24.4	900	882	868	844	811	765	702	618	527	454	396	291	223	176	142
	1,300,000	Common	27.2	720	710	704	691	674	650	617	574	520						
Elm, slippery and American	1,200,000	Select	27.5	650	642	636	625	611	590	562	526	480	419	365	268	206	162	132
	1,200,000	Common	30.8	520	516	513	507	500	489	475	456	432	402	364				
Fir, commercial white	1,100,000	Select	27.4	600	593	587	577	563	544	518	484	440	385	335	246	188	149	121
	1,100,000	Common	30.7	480	476	473	468	461	451	438	420	397	369	334				

Gum, red, black, and tupelo	1,200,000	Select	27.5	650	642	636	625	611	590	562	526	489	419	365	268	206	162	132
	1,200,000	Common	30.8	520	516	513	507	500	489	475	456	432	402	364				
Hemlock, eastern	1,100,000	Select	27.4	600	593	587	577	563	541	518	484	440	385	335	246	188	149	121
	1,100,000	Common	30.7	480	476	473	468	461	451	438	420	397	369	334				
Hemlock, western	1,400,000	Select	26.8	800	790	780	766	746	718	679	629	564	490	426	313	240	189	153
	1,400,000	Common	30.0	640	634	630	623	612	598	578	552	520	478	427				
Larch, western	1,300,000	Select	25.8	800	788	777	761	737	706	660	602	527	454	396	291	223	176	142
	1,300,000	Common	28.8	640	634	628	620	608	591	568	538	500	452					
Maple, sugar and black	1,600,000	Select	27.0	900	888	878	863	840	810	768	713	642	559	487	358	274	216	175
	1,600,000	Common	30.2	720	714	708	701	690	674	652	624	588	543	486				
Maple, red and silver	1,100,000	Select	27.5	600	593	587	577	563	544	518	484	440	384	335	246	188	149	121
	1,100,000	Common	30.7	480	476	473	468	461	451	438	420	398	369	334				
Oak, commercial red and white	1,500,000	Select	27.7	800	790	783	771	753	728	695	650	595	524	457	336	257	203	164
	1,500,000	Common	31.1	640	636	631	625	616	603	586	563	534	498	453				
Pine, southern yellow	1,600,000	Select	26.9	907	895	885	869	847	815	772	716	644	559	487	358	274	216	175
	1,600,000	Common	31.1	680	675	670	664	655	641	624	600	569	531	484				
Pine, southern yellow (dense)	1,600,000	Select	25.8	992	976	963	943	913	872	816	742	649	559	487	358	274	216	175
	1,600,000	Common	28.8	793	785	778	768	753	732	703	666	618	557					
Pine, northern white, western white, western yellow, and sugar.	1,000,000	Select	25.1	650	639	629	614	593	564	523	471	406	350	304	224	171	135	110
	1,000,000	Common	28.1	520	514	510	502	491	476	455	428	394	350	304				
Pine, Norway	1,200,000	Select	26.5	700	690	682	669	651	625	591	545	487	419	365	268	206	162	132
	1,200,000	Common	29.7	560	555	551	544	535	521	504	480	450	413					
Redwood	1,200,000	Select	25.6	750	738	728	712	689	657	614	557	484	419	365	268	206	162	132
	1,200,000	Common	28.6	600	594	588	581	569	552	531	502	465	419	365				
Spruce, red, white, and Sitka	1,200,000	Select	27.5	650	642	636	625	611	590	562	526	480	419	365	268	206	162	132
	1,200,000	Common	30.8	520	516	513	507	500	489	475	456	432	402	364				
Sycamore	1,200,000	Select	27.5	650	642	636	625	611	590	562	526	480	419	365	268	206	162	132
	1,200,000	Common	30.8	520	516	513	507	500	489	475	456	432	402	364				
Tamarack	1,300,000	Select	25.8	800	788	777	761	737	706	660	602	527	454	396	291	223	176	142
	1,300,000	Common	28.8	640	634	628	620	608	591	568	538	500	452					

SAFE WORKING STRESSES FOR COLUMNS IN AN OCCASIONALLY WET AND QUICKLY DRY CONDITION

				Pounds per square inch														
Ash, commercial white	1,500,000	Select	24.8	1,000	982	967	943	908	860	795	709	608	524	457	336	257	203	164
	1,500,000	Common	27.8	800	790	783	771	753	728	695	650	595						
Aspen and largetooth aspen	900,000	Select	25.9	550	542	534	523	507	484	454	415	365	315	274	201	154	122	99
	900,000	Common	29.0	440	436	432	426	418	407	392	371	345	312					
Basswood	900,000	Select	25.9	550	542	534	523	507	484	454	415	365	315	274	201	154	122	99
	900,000	Common	29.0	440	436	432	426	418	407	392	371	345	312					
Beech	1,600,000	Select	24.4	1,100	1,078	1,060	1,033	993	937	861	762	649	559	487	358	274	216	175
	1,600,000	Common	27.4	880	870	860	846	824	796	756	705	639	559					
Birch, yellow and sweet	1,600,000	Select	24.4	1,100	1,078	1,060	1,033	993	937	861	762	649	559	487	358	274	216	175
	1,600,000	Common	27.4	880	870	860	846	824	796	756	705	639						

[1] Basic provisions for American lumber standards grades are published by the U. S. Department of Commerce in Simplified Practice Recommendation No. 16, Lumber, revised July 1, 1926; specifications for grades conforming to American lumber standards are published in the 1927 Standards of the American Society for Testing Materials, and in American Railway Engineering Association Bulletin, Vol. 27, No. 284, dated February, 1926.

[2] Species which are nonresistant to decay, used under these conditions without adequate preservative treatment, will lose strength and require frequent replacement.

[3] The modulus of elasticity values given are the averages for the species.

TABLE 8.—*Working stresses for timber conforming to the basic provisions for Select and Common grades of structural material of American lumber standards*—Continued

SAFE WORKING STRESSES FOR COLUMNS IN AN OCCASIONALLY WET AND QUICKLY DRY CONDITION—Continued

Species	Modulus of elasticity	Grades	Value of K	When ratio of length to least dimension $\frac{L}{d}$ is— Short columns	12	14	16	18	20	22	24	26	28	30	35	40	45	50
				Pounds per square inch														
Cedar, Alaska	1,200,000	Select	25.6	750	738	728	712	689	657	614	557	486	419	365	268	206	162	132
	1,200,000	Common	28.7	600	591	588	581	569	552	531	502	465						
Cedar, western red	1,600,000	Select	24.2	700	686	674	656	629	592	542	476	405	350	304	224	171	135	110
	1,060,000	Common	27.1	560	553	547	538	524	505	479	445	402						
Cedar, northern and southern white	800,000	Select	25.7	500	492	485	474	459	438	409	372	324	280	244	179	137	108	88
	800,000	Common	28.6	400	396	392	387	379	368	351	335	310	279					
Cedar, Port Orford	1,200,000	Select	24.6	825	808	795	771	744	702	645	572	487	419	365	268	206	162	132
	1,200,000	Common	27.4	660	652	615	634	618	597	567	529	479						
Chestnut	1,000,000	Select	24.3	700	686	674	656	629	592	542	476	405	350	304	224	171	135	110
	1,000,000	Common	27.0	560	553	547	538	524	505	479	445	402						
Cottonwood, eastern and black	900,000	Select	25.9	550	512	534	523	507	481	454	415	365	315	274	201	154	122	99
	900,000	Common	29.0	440	436	432	426	418	407	392	371	345	312					
Cypress, southern	1,200,000	Select	22.2	1,000	972	917	910	856	781	679	571	486	419	365	268	206	162	132
	1,200,000	Common	24.8	800	786	773	751	726	688	636	567							
Douglas fir (western Washington and Oregon)	1,600,000	Select	24.8	1,067	1,018	1,031	1,006	969	917	848	757	649	559	487	358	274	216	175
	1,600,000	Common	28.6	800	792	785	774	758	737	708	670	620	558					
Douglas fir (dense)	1,600,000	Select	23.7	1,167	1,142	1,120	1,087	1,038	971	880	761	649	559	487	358	274	216	175
	1,600,000	Common	26.6	933	920	909	892	867	833	737	726	647						
Douglas fir (Rocky Mountain type)	1,200,000	Select	24.8	800	786	771	753	726	688	636	566	486	419	365	268	206	162	132
	1,200,000	Common	27.8	640	632	627	617	602	582	556	522	476						
Elm, rock	1,300,000	Select	22.0	1,100	1,068	1,041	999	937	851	737	618	527	454	396	291	223	176	142
	1,300,000	Common	24.6	880	863	849	828	798	752	691	617	527						
Elm, slippery and American	1,200,000	Select	25.6	750	738	728	712	689	657	614	557	486	419	365	268	206	162	132
	1,200,000	Common	28.7	600	594	588	581	569	552	531	502	465						
Fir, commercial white	1,100,000	Select	25.4	700	689	678	664	641	611	569	515	446	385	335	246	188	149	121
	1,100,000	Common	28.4	560	554	549	542	530	515	493	465	430	384					
Gum, red, black, and tupelo	1,200,000	Select	25.6	750	738	728	712	689	657	614	557	486	419	365	268	206	162	132
	1,200,000	Common	28.7	600	594	588	581	569	552	531	502	465						
Hemlock, eastern	1,100,000	Select	25.4	700	689	678	664	641	611	569	515	446	385	335	246	188	149	121
	1,100,000	Common	28.4	560	554	549	542	530	515	493	465	430	384					
Hemlock, western	1,400,000	Select	25.3	900	885	872	852	823	783	728	658	567	490	426	313	240	189	153
	1,400,000	Common	28.3	720	712	706	696	680	660	632	595	549	489					
Larch, western	1,300,000	Select	23.1	1,000	976	955	923	877	813	726	618	527	454	396	291	223	176	142
	1,300,000	Common	25.8	800	788	777	761	737	706	660	602							
Maple, sugar and black	1,600,000	Select	21.4	1,100	1,078	1,060	1,033	993	937	861	762	649	559	487	358	274	216	175
	1,600,000	Common	27.4	880	870	860	846	824	796	756	705	639						

Maple, red and silver	1,100,000	Select	25.4	700	689	678	664	641	611	569	515	446	384	335	246	188	149	121
	1,100,000	Common	28.4	560	554	549	542	530	515	493	465	430						
Oak, commercial red and white	1,500,000	Select	26.1	900	886	876	859	834	798	751	688	609	524	457	336	257	203	164
	1,500,000	Common	29.3	720	714	708	698	686	668	641	612	571	520					
Pine, southern yellow	1,600,000	Select	24.8	1,067	1,048	1,031	1,006	969	917	848	757	619	559	487	358	274	216	175
	1,600,000	Common	28.6	800	792	785	774	758	737	708	670	620	558					
Pine, southern yellow (dense)	1,600,000	Select	23.7	1,167	1,142	1,120	1,087	1,038	971	880	761	619	559	487	358	274	216	175
	1,600,000	Common	26.6	933	920	909	892	867	833	787	726	647						
Pine, northern white, western white, western yellow, and sugar.	1,000,000	Select	23.4	750	733	718	695	663	617	555	476	406	350	304	224	171	135	110
	1,000,000	Common	26.2	600	591	583	572	556	532	500	459	405						
Pine, Norway	1,200,000	Select	24.8	800	786	774	753	726	688	636	566	486	419	365	268	206	162	132
	1,200,000	Common	27.8	640	632	627	617	602	582	556	522	476						
Redwood	1,200,000	Select	23.4	900	879	861	834	796	741	666	571	486	419	365	268	206	162	132
	1,200,000	Common	26.1	720	709	700	686	667	639	600	551							
Spruce, red, white, and Sitka	1,200,000	Select	25.6	750	738	728	712	689	657	614	557	486	419	365	268	206	162	132
	1,200,000	Common	28.7	600	594	588	581	569	552	531	502	465	419					
Sycamore	1,200,000	Select	25.6	750	738	728	712	689	657	614	557	486	419	365	268	206	162	132
	1,200,000	Common	28.7	600	594	588	581	569	552	531	502	465						
Tamarack	1,300,000	Select	24.3	900	882	868	844	811	765	702	619	527	454	396	291	223	176	142
	1,300,000	Common	27.2	720	711	703	691	674	650	617	575	520						

SAFE WORKING STRESSES FOR COLUMNS USED IN DRY INSIDE LOCATIONS

Pounds per square inch

Ash, commercial white	1,500,000	Select	23.7	1,100	1,076	1,055	1,023	978	913	827	714	608	524	457	336	257	203	164
	1,500,000	Common	26.5	880	868	857	840	818	784	740	682	607						
Aspen and largetooth aspen	900,000	Select	23.0	700	682	668	645	612	566	505	428	365	315	274	201	154	122	99
	900,000	Common	25.7	560	551	541	532	515	492	460	418							
Basswood	900,000	Select	23.0	700	682	668	645	612	566	505	428	365	315	274	201	154	122	99
	900,000	Common	25.7	560	551	544	532	515	492	460	418							
Beech	1,600,000	Select	23.4	1,200	1,172	1,148	1,112	1,061	988	888	761	649	559	487	358	274	216	175
	1,600,000	Common	26.2	960	946	933	915	889	852	801	734							
Birch, yellow and sweet	1,600,000	Select	23.4	1,200	1,172	1,148	1,112	1,061	988	888	761	649	559	487	358	274	216	175
	1,600,000	Common	26.2	960	946	933	915	889	852	801	734							
Cedar, Alaska	1,200,000	Select	24.8	800	786	774	753	726	688	636	566	486	419	365	268	206	162	132
	1,200,000	Common	27.8	640	632	627	617	602	582	556	522	476						
Cedar, western red	1,000,000	Select	24.2	700	686	674	656	629	592	542	476	405	350	304	224	171	135	110
	1,000,000	Common	27.1	560	553	547	538	524	505	479	445	402						
Cedar, northern and southern white	800,000	Select	24.5	550	540	530	516	496	468	430	381	324	280	244	179	137	108	88
	800,000	Common	27.3	440	435	430	423	412	398	378	353	320						
Cedar, Port Orford	1,200,000	Select	23.4	900	879	861	834	796	741	666	571	487	419	365	268	206	162	132
	1,200,000	Common	26.2	720	709	700	686	667	639	609	551							
Chestnut	1,000,000	Select	22.7	800	779	762	734	694	638	564	476	405	350	304	224	171	135	110
	1,000,000	Common	25.3	640	629	620	606	586	557	519	468							
Cottonwood, eastern and black	900,000	Select	23.0	700	682	668	645	612	566	505	428	365	315	274	201	154	122	99
	900,000	Common	25.7	560	551	544	532	515	492	460	418							
Cypress, southern	1,200,000	Select	21.2	1,100	1,063	1,030	984	909	810	679	571	486	119	365	268	206	162	132
	1,200,000	Common	23.7	880	861	843	818	781	729	658								

TABLE 8.—*Working stresses for timber conforming to the basic provisions for Select and Common grades of structural material of American lumber standards*—Continued

SAFE WORKING STRESSES FOR COLUMNS USED IN DRY INSIDE LOCATION—Continued

Species	Modulus of elasticity	Grades	Value of K	When ratio of length to least dimension $\frac{L}{d}$ is— Short columns	12	14	16	18	20	22	24	26	28	30	35	40	45	50
				Pounds per square inch														
Douglas fir (western Washington and Oregon)	1,600,000	Select	23.7	1,173	1,147	1,125	1,092	1,042	974	882	761	649	559	487	358	274	216	175
	1,600,000	Common	27.3	880	869	860	846	825	796	757	706	640						
Douglas fir (dense)	1,600,000	Select	22.6	1,283	1,249	1,221	1,177	1,112	1,023	902	761	649	559	487	358	274	216	175
	1,600,000	Common	25.3	1,027	1,010	995	972	939	894	832	750							
Douglas fir (Rocky Mountain type)	1,200,000	Select	24.8	800	786	774	753	726	688	636	566	486	419	365	268	206	162	132
	1,200,000	Common	27.8	640	632	627	617	602	582	556	522	476						
Elm, rock	1,300,000	Select	21.1	1,200	1,158	1,122	1,067	988	877	731	618	527	454	396	291	223	176	142
	1,300,000	Common	23.6	960	939	920	892	852	795	718								
Elm, slippery and American	1,200,000	Select	24.8	800	786	774	753	726	688	636	566	486	419	365	268	206	162	132
	1,200,000	Common	27.8	640	632	627	617	602	582	556	522	476						
Fir, commercial white	1,100,000	Select	25.4	700	689	678	664	641	611	569	515	446	385	335	246	188	149	121
	1,100,000	Common	28.4	560	554	549	512	530	515	493	465	430	384					
Gum, red, black, and tupelo	1,200,000	Select	24.8	800	786	774	753	726	688	636	566	486	419	365	268	206	162	132
	1,200,000	Common	27.8	640	632	627	617	602	582	556	522	476						
Hemlock, eastern	1,100,000	Select	25.4	700	689	678	664	641	611	569	515	446	385	335	246	188	149	121
	1,100,000	Common	28.4	560	551	549	542	530	515	493	465	430	384					
Hemlock, western	1,400,000	Select	25.3	900	885	872	852	823	783	728	658	567	490	426	313	240	189	153
	1,400,000	Common	28.3	720	712	706	696	680	660	632	595	549	489					
Larch, western	1,300,000	Select	22.0	1,100	1,068	1,041	999	937	851	737	618	527	454	396	291	223	176	142
	1,300,000	Common	24.6	880	863	849	828	798	752	694	617							
Maple, sugar and black	1,600,000	Select	23.4	1,200	1,172	1,148	1,112	1,061	988	888	761	649	559	487	358	274	216	175
	1,600,000	Common	26.2	960	946	933	915	889	852	801	734							
Maple, red and silver	1,100,000	Select	23.8	800	782	768	746	712	666	604	524	446	384	335	246	188	149	121
	1,100,000	Common	26.6	640	631	623	612	594	572	540	498							
Oak, commercial red and white	1,500,000	Select	24.8	1,000	982	967	943	908	860	795	709	608	521	457	336	257	203	164
	1,500,000	Common	27.8	800	790	783	771	753	728	695	650	595						
Pine, southern yellow	1,600,000	Select	23.7	1,173	1,147	1,125	1,092	1,042	974	882	761	649	559	487	358	274	216	175
	1,600,000	Common	27.3	880	869	860	846	825	796	757	706	640						
Pine, southern yellow (dense)	1,600,000	Select	22.6	1,283	1,249	1,221	1,177	1,112	1,023	902	761	649	559	487	358	274	216	175
	1,600,000	Common	25.3	1,027	1,019	995	972	939	894	832	750							
Pine, northern white, western white, western yellow, and sugar.	1,000,000	Select	23.4	750	733	718	695	663	617	555	476	406	350	304	224	171	135	110
	1,000,000	Common	26.2	600	591	583	572	556	532	500	459	405						
Pine, Norway	1,200,000	Select	24.8	800	786	771	753	726	688	636	566	486	419	365	268	206	162	132
	1,200,000	Common	27.8	640	632	627	617	602	582	556	522	476						
Redwood	1,200,000	Select	22.2	1,000	972	947	910	856	781	679	571	486	419	365	268	206	162	132
	1,200,000	Common	24.8	800	786	773	754	726	688	636	567							

Spruce, red, white, and Sitka	1,200,000	Select	24.8	800	786	774	753	726	688	636	566	486	419	365	268	206	162	132
	1,200,000	Common	27.8	640	632	627	617	602	582	556	522	476						
Sycamore	1,200,000	Select	24.8	800	786	774	753	726	688	636	566	486	419	365	268	206	162	132
	1,200,000	Common	27.8	640	632	627	617	602	582	556	522	476						
Tamarack	1,300,000	Select	23.1	1,000	976	955	923	877	813	726	618	527	454	396	291	223	176	142
	1,300,000	Common	25.8	800	788	777	761	737	706	660	602							

Explanation of Table 8.—The values in the table were obtained by the use of the Forest Products Laboratory fourth-power parabolic formula and the Euler formula for long columns, pin-ended conditions.

The Forest Products Laboratory fourth-power parabolic formula

$$\frac{P}{A}=S\left\{1-\frac{1}{3}\left(\frac{L}{Kd}\right)^4\right\}$$

The Euler formula

$$\frac{P}{A}=\frac{0.274E}{\left(\frac{L}{d}\right)^2}$$

Legend

P=maximum load on column in pounds.
A=cross-sectional area in square inches.
S=compression-parallel stress in pounds per square inch.
L=unsupported length in inches.
d=least dimension in inches.
E=modulus of elasticity in pounds per square inch.
K=constant for given species, grade, and condition of service.

The stresses have a factor of safety of 4 based on the average crushing stress for short columns and a factor of 3 based on the average modulus of elasticity of the species. With any given species the modulus of elasticity is the same for the two grades and three conditions of use since the influence of moisture and defects on modulus of elasticity is relatively small. Therefore, as an Euler column, each species has for a given $\frac{L}{d}$ a single stress for both grades and the three conditions of service.

Round columns.—The values in the table may be applied to round columns by reducing the cross-sectional area of the column to an equivalent square timber, d, the side of the square being taken as seven-eighths of the diameter, measured one-third the length from the small end. The crushing stress at the small end must not exceed the allowable stress for a short column.

A composite curve of Euler's curve and the Forest Products Laboratory fourth-power parabolic curve is shown in Figure 1. The eighth-power parabolic curve is also given together with curves representing several other column formulas. Curves 2, 3, 4, and 7 are all tangent to the Euler curve and are simply variations of the general parabolic equation. The eighth-power curve assumes a fiber stress at elastic limit of 80 per cent of the maximum compression stress; the fourth power assumes an elastic limit stress two-thirds the maximum; J. B. Johnson's or the second-power parabola, a stress of one-half the maximum; and T. H. Johnson's straight line or first-power curve, an elastic limit stress of one-third the maximum.

RELATION OF THE PARABOLIC-EULER FORMULA TO TESTS OF COLUMNS HAVING DIFFERENT $\frac{L}{d}$ RATIOS

The conceptions back of the Forest Products Laboratory parabolic-Euler formula have been given. But how accurately does the formula represent the action of columns under test? Knowing the crushing strength, the fiber stress at elastic limit, and the stiffness of the material how closely can the strength of columns of the same material of any length be estimated? Is the formula amply conservative?

To answer these questions Figure 2 has been plotted.

In this figure an attempt is made to eliminate the variability of the material, which is taken care of by the grading rules and factor of safety, and to show only the relation of the strength of the column to its slenderness, or ratio of length to least dimension, which is conceived to be the function of a column formula. The data obtained from the tests of the columns of structural sizes, which have been described here, are too limited in ratios of length to least dimension to establish the relation of $\frac{L}{d}$ to strength of a column. Other tests made primarily on dry Sitka spruce and Douglas fir, in which the range and the data necessary to establish such a relationship were afforded, have therefore been used. The Euler formula requires that the modulus of elasticity or stiffness be known. This can be determined with a fair degree of accuracy for both clear and defective material. All but the lowest grade 12 by 12 inch by 24-foot columns previously described here come within the Euler class and even the timbers with the largest knots are so close to being Euler columns that they, and also the 2 by 2 by 48 inch clear pieces cut from them, are included in Figure 2. Four hundred and eighty tests are represented by the distribution area at an $\frac{L}{d}$ ratio of 24. All the other points represent single tests.

The parabolic portion of the curve assumes that the crushing strength of a short block is known and also the fiber stress at elastic limit, and the stiffness. It is possible by means of matched pieces to determine all these properties for the clear wood within any column and to predict by the formula what a column of any length should support, the difference between the test load and the estimated load being due to experimental errors and to the inaccuracy of the formula. The inaccuracy in predicting the crushing strength of short blocks

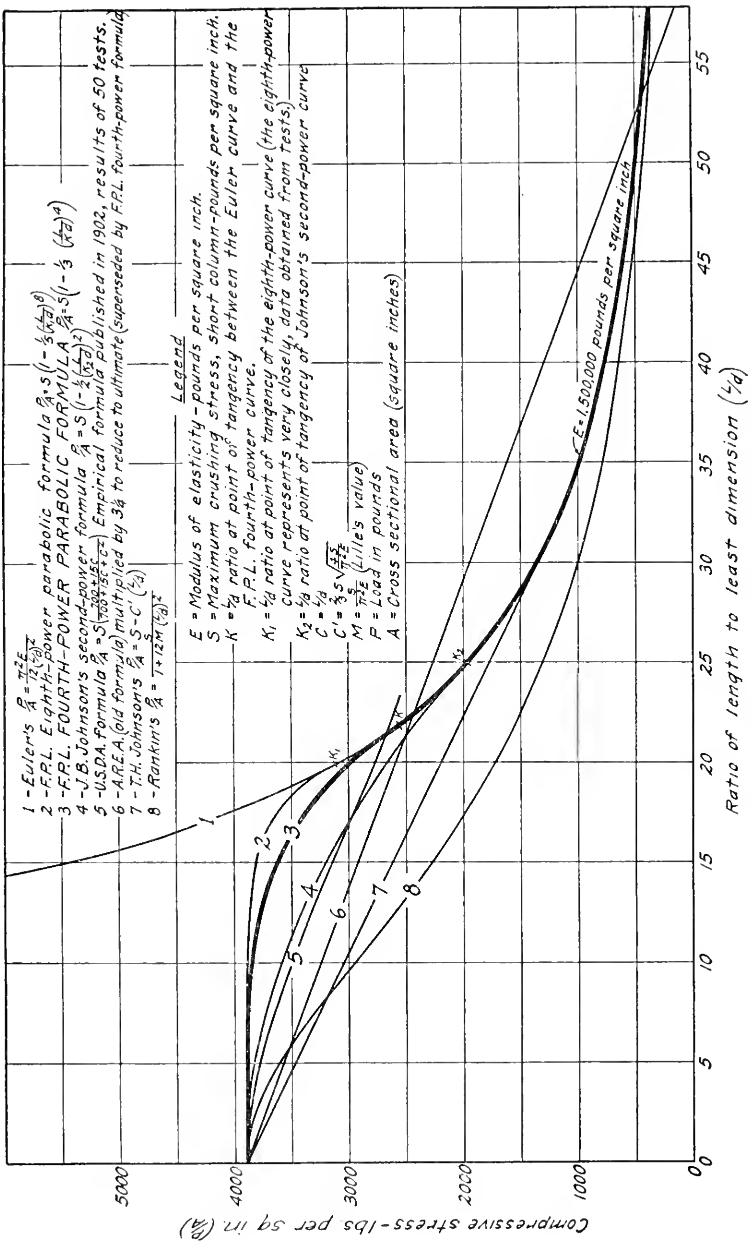


FIGURE 1.—Column formulas and the resultant curves

containing large knots is so great that no attempt was made to include the results of tests of commercial timbers in this portion of the curve.

The points on Figure 2 do not represent actual test values but were obtained indirectly by substituting in the general formula the constants obtained from matched sticks (except that for convenience the fiber stress at elastic limit was taken as 80 per cent of the ultimate whereas it as a rule is somewhat higher) and then by calculating the expected load for each column and the percentage that the actual test load differed from the calculated load. This percentage is represented in Figure 2 by the distance the test point representing a particular test is from the average eighth-power curve. Thus, the points represent experimental errors and formula inaccuracy but do not represent the variability of the material. The point at about $\frac{L}{d}=9$ was obtained from a test with a slightly eccentric load, which accounts for its being below the curve.

It was found that with an Euler column on a knife edge bearing the degree of conformity to the expected load is primarily a matter of the refinement used in determining the stiffness of the test specimen and care in making the column test.

The conformity of intermediate columns is very close when the maximum crushing strength, fiber stress at elastic limit, and stiffness for the individual pieces are all known and the general form of the equation is used. The points show that even the eighth-power equation is low for clear, dry spruce or Douglas fir. This conforms to laboratory test data, which shows that generally such material has a fiber stress at elastic limit more than 80 per cent of the ultimate. It is not practical to use different powers in the parabolic formula and the fourth-power parabola is recommended for use, since material of some species when green will have a fiber stress at elastic limit only two-thirds the ultimate for short columns; that is, under some conditions, the fourth-power parabola will be correct, and the eighth power unsafe.

Although the fourth-power formula may also be used to determine the safe stress for short columns, it is recommended that the crushing strength for short columns be used instead for all columns with a slenderness ratio of 11 or less, since the error would seldom be more than 1½ per cent of that obtained by the use of the formula.

RELATION OF THE FOREST PRODUCTS LABORATORY FOURTH-POWER PARABOLIC-EULER COLUMN FORMULA TO TESTS ON SOUTHERN YELLOW PINE AND DOUGLAS FIR STRUCTURAL TIMBERS

The relation of the Forest Products Laboratory fourth-power formula to the tests on southern yellow pine and Douglas fir structural timbers is shown in Figures 3 to 6, inclusive, which present data from tests on the nominal 12 by 12 inch columns of the various lengths investigated. The points on the figures represent individual tests. The large spread in these points is due to the fact that the test material ranged in grade from clear and dense to knotty and light. Furthermore, all the short and intermediate columns were cut from the long columns after test and some specimens may have been slightly injured and therefore may have given lower loads in test than would be expected.

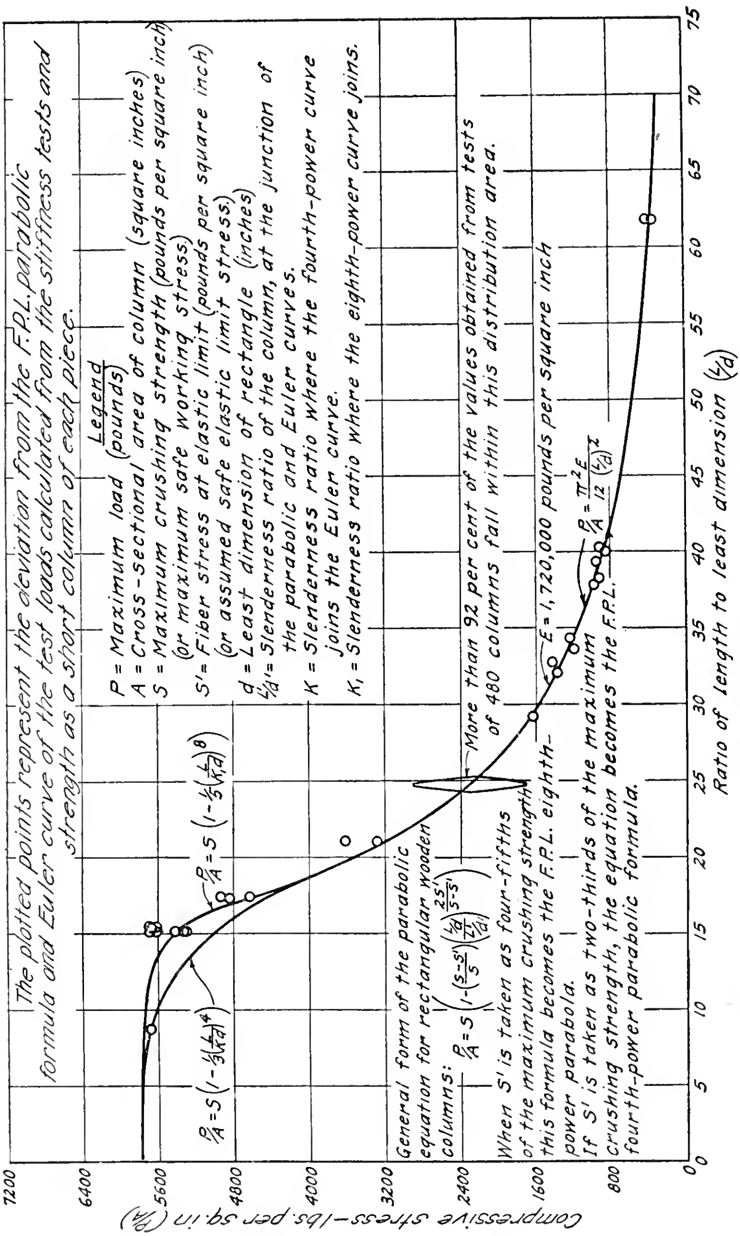


FIGURE 2.—Relation of the Forest Products Laboratory parabolic-Euler formulas to test data from columns of various $\frac{L}{d}$ ratios

Two ultimate stress curves which show the strength of columns for various $\frac{L}{d}$ ratios are plotted on each chart; one approximately through the average test values for the Select grade (*3*) of each of the three groups of columns, and the second through the minimum values of each group of columns irrespective of grade. It may be seen that the average test loads for the long columns fall slightly below the curves. This is due to the technic employed in the tests which is explained on page 14.

A comparison between the curves in Figures 3 and 4 and between those in Figures 5 and 6 shows a marked similarity in column strength between the two species. The curves also illustrate that the intermediate and 2-foot southern yellow pine columns in both the green and air-dry conditions sustained slightly greater ultimate compressive stresses than the Douglas fir columns of similar lengths and that the Douglas fir long columns had somewhat greater stiffness than the southern yellow pine long columns.

The lower curves in Figures 3 to 6 represent recommended safe working stresses for a dense select grade of southern yellow pine and Douglas fir columns.

END CONDITIONS, ECCENTRIC LOADING, AND CROOKED COLUMNS

In the present study the 24-foot columns were tested with pin-ended bearings as shown in Plate 2. Under these conditions the columns were carefully loaded in such a way that bending could take place freely in but one plane. Theoretically, a column of any length tested in this manner would carry less load than if the ends were carefully surfaced and the column tested with flat-ended bearings. The tests of the intermediate and short columns showed that up to a limit of 11 for $\frac{L}{d}$ any increase in strength caused by flat-end conditions is negligible. The reduction in strength of a wooden column resulting from imperfect end surfaces, crooks, eccentric loading, or any other condition that will result in combined bending and compression, is not so great as might be expected. Tests have shown that a timber, when subjected to combined bending and compression, develops a higher stress at both the elastic limit and maximum load than when subjected to compression only (*5*). This does not imply that crooks and eccentricity should be without restriction, but it should relieve anxiety as to the influence of imperfect end conditions and the influence of crooks such as those common in structural columns.

ROUND COLUMNS

It has been proven by tests (*4*) that round and square wooden members of the same cross-sectional area will carry the same loads in both bending and in compression, and have approximately the same stiffness. In the design of round columns the procedure is to design first for a square column and then to use a diameter of round column which will give the equivalent area of the square; namely, $\frac{2}{\sqrt{\pi}}$ times the side of the square. If the column is tapered, the diameter should be taken at one-third of the length from the small end. This will give a diameter of round column necessary to prevent failure from buckling. The stress at the small end of the column which will result from the assumed load should also be computed since it must not exceed the allowable stress for a short column.

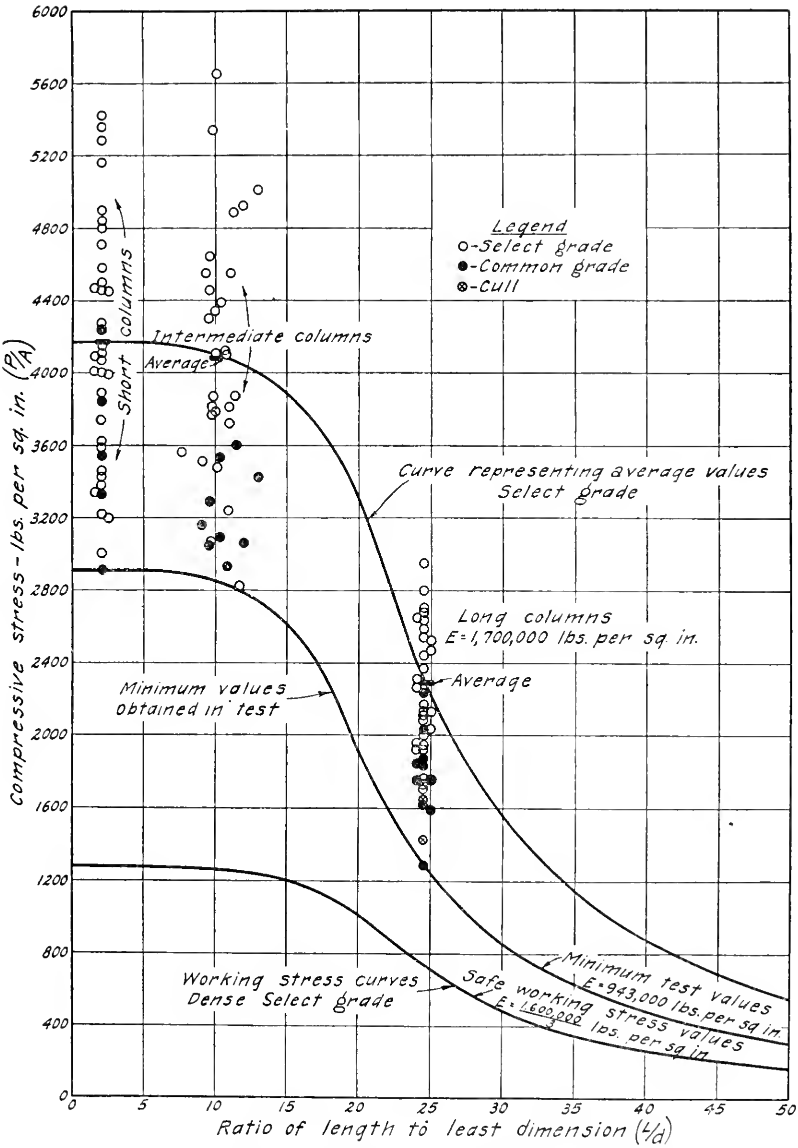


FIGURE 3.—Relation of Forest Products Laboratory fourth-power formula to the individual tests of 12 by 12 inch short, intermediate, and long columns of southern yellow pine in green condition

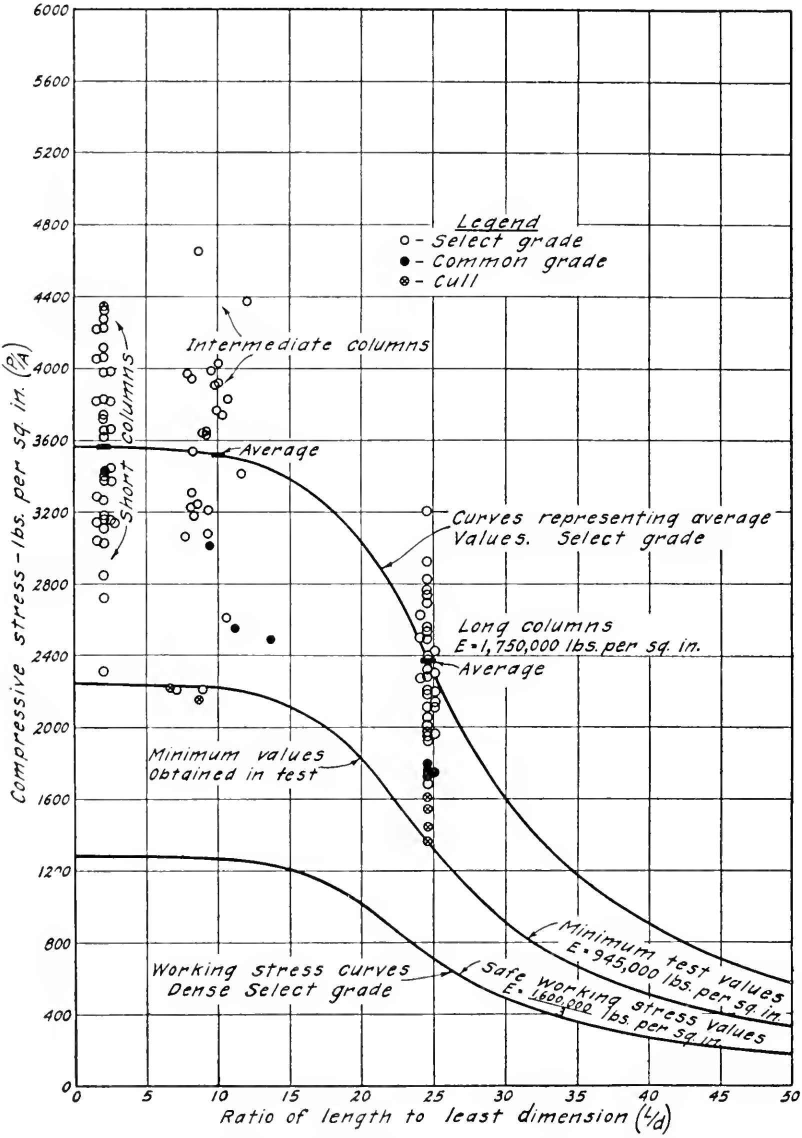


FIGURE 4. Relation of Forest Products Laboratory fourth-power formula to the individual tests of 12 by 12 inch short, intermediate, and long columns of Douglas fir in green condition

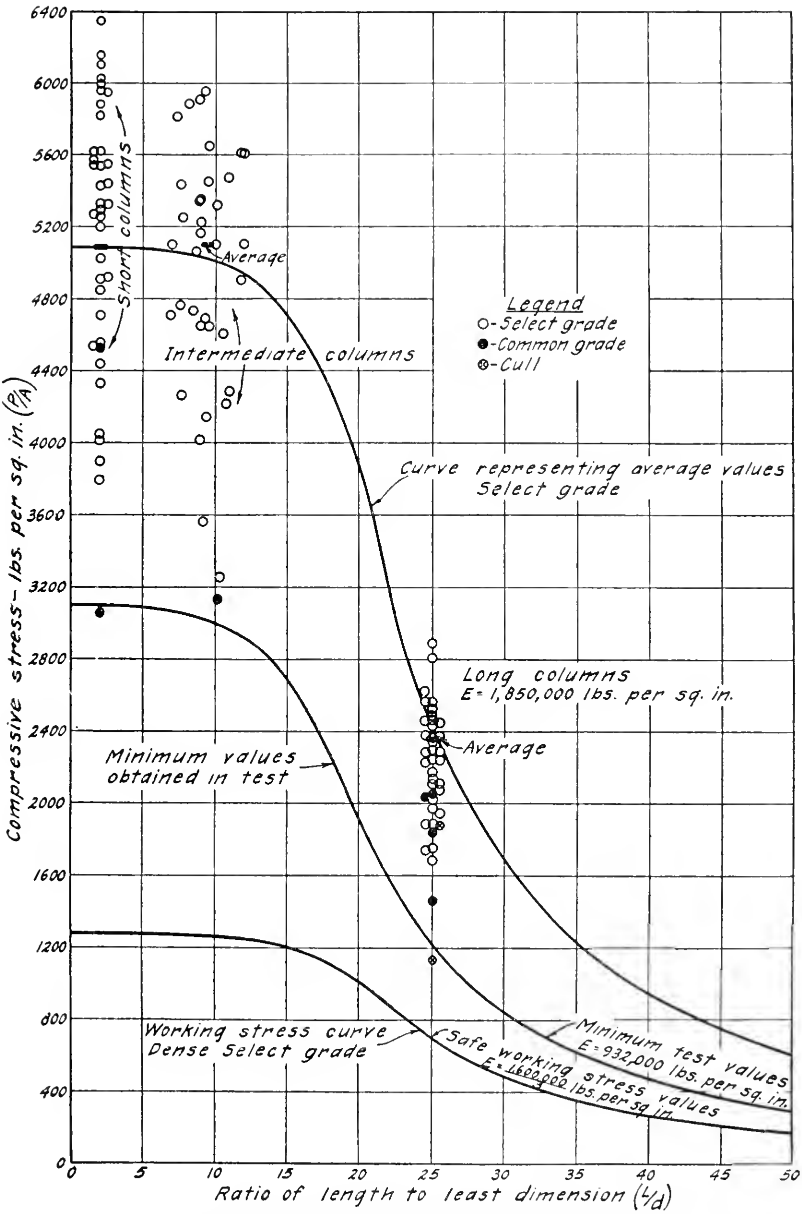


FIGURE 5.—Relation of Forest Products Laboratory fourth-power formula to the individual tests of 12 by 12 inch short, intermediate, and long columns of southern yellow pine in air-dry condition

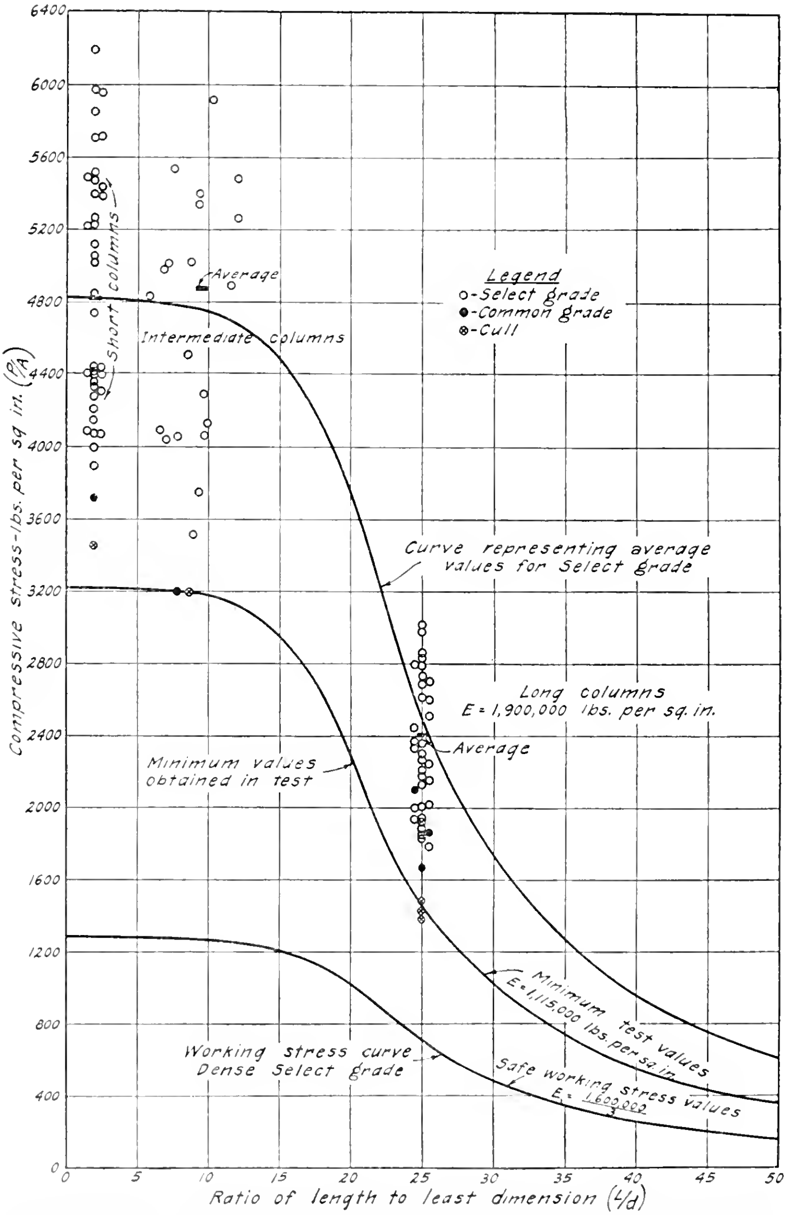


FIGURE 6.—Relation of Forest Products Laboratory fourth-power formula to the individual tests of 12 by 12 inch short, intermediate, and long columns of Douglas fir in air-dry condition

CONCLUSIONS

The tests on large timber columns confirm the Forest Products Laboratory column formula and in addition justify the following conclusions:

In long columns, where stiffness instead of crushing strength is the controlling factor, the loss in strength on account of knots is relatively small as compared to that for shorter specimens. The loss would be negligible in long columns of the common grade having a slenderness ratio of 30 or more to 1 and in high-grade columns with a slenderness ratio of approximately 20 to 1.

The effect of knots on the strength of short columns is proportional to the reduction in cross-sectional area that would result if all the knots in any 6 inches of the length were removed from the cross section.

A column with a slenderness ratio of 11 to 1 will sustain approximately the same load as a shorter column of the same cross-sectional area.

Long columns: Within the elastic limit of the material the best interpretation of the behavior of long columns is the Euler formula.

The decrease in cross section of an Euler column, on account of seasoning, largely offsets the increase in strength which accompanies the seasoning.

Intermediate columns: The most practical expression of the behavior of intermediate columns appears to be the Forest Products Laboratory fourth-power formula.

Southern yellow pine and Douglas fir columns of the type and grade tested are practically equal in strength.

APPENDIX

DETAIL TEST PROCEDURE

MAJOR TESTS

All long columns were surfaced on four sides, cut to nominal 24 feet, and the two ends planed perpendicular to one of the sides. The butt and top ends of each timber were marked A and B, respectively. The green material was surfaced to 11¾ by 11¾ inches in section and the air-seasoned to 11½ and 11½ inches. These dimensions are nominal, the actual sizes being somewhat less, particularly in the air-seasoned timbers, depending upon the amount surfaced off on account of twist. A vertical type testing machine capable of applying 1,000,000 pounds load was used for the tests.

STIFFNESS TEST

Each timber, prior to the long-column test, was tested in bending with center loading. The span was 200 inches (16 feet 8 inches), and the maximum load applied was 5,000 pounds. Two sets of data were taken with the top and butt ends of the timber, respectively, in the overhang. Deflections were read from scales attached to the two vertical faces of the timber. From these data the modulus of elasticity (E) of each timber was calculated; the load that the timber should carry as a pin-ended connected long column was then determined by means of Euler's formula. With a span of 200 inches, the static load for a deflection of 0.2 inch is approximately 1 per cent of the calculated Euler load.

The top face of the test specimen, as it was supported in the testing machine and as the operator faced the butt end of the timber, was marked *a*. The remaining three faces were marked *b*, *c*, and *d*, in clockwise rotation. The weight of the timber and the cross-sectional dimensions of the two ends and of the center were then recorded.

LONG-COLUMN TESTS

The long-column tests were made with pin-ended bearings. (Pl. 2.) The timber was placed butt end down upon a special roller bearing with the *a* and *c* faces of the timber turned so that they were either the compression or the tension faces. The method of centering of the column in the machine was by trial. The center of the column end was placed over the center of the bearing and an end load applied at the rate of 0.014 inch per minute. If a deflection of more than 0.01 inch occurred with a load of 100,000 pounds or less, the column was shifted slightly and the process repeated until zero deflection at the middle of the height was obtained with that load. Another load was then applied and deflections were read at the middle and quarter points of the column. Loads and deflections were recorded at every 10,000 pounds until near maximum. The maximum load and corresponding deflection were then recorded. After maximum load, the loads and deflections were read at irregular intervals until a deflection of 5 inches had been reached when the screws of the testing machine were stopped. The deflection of the column, however, continued to increase, and recording of the loads and of deflections was continued until the movement had virtually ceased. The column was then taken out of the machine and the size and location of each knot and the location and extent of failure were sketched. The section of the timber containing the failure was then marked off and the longer end section selected as the intermediate-length column. The short end was marked into a 2-foot section and a section for the minor tests. In some timbers, because of the character of the failure, the shorter sections were taken from other portions of the long column. The four faces of the column were then photographed. (See pl. 1 for method of marking.) In order to make the air-seasoned material deflect from the beginning of the test the columns were set 0.07 inch off center. This slight change in the method of procedure prevented the column from reaching a state of unstable equilibrium.

INTERMEDIATE COLUMN TESTS

The intermediate columns varied in length from 6 to 13 feet, approximately. The test was similar to that of the long column. (Pl. 3.) Care was taken to place the specimen with the faces in the same relative positions as in the long-column test. Deflections were read at the center of the column up to maximum load, in the same manner as with the long columns. Deflections were not read after maximum load had been reached.

TWO-FOOT COLUMN TESTS

These tests were performed with the column centered on a heavy stationary plate. The load was applied centrally at the rate of 0.032 inch per minute, and the amount of compression in the column was obtained by measuring the descent of the moving head by means of a deflectometer. (Pl. 4.)

MINOR TESTS

For each timber the following tests were made upon the clear straight-grained material cut from the section (pl. 1) reserved for minor tests:

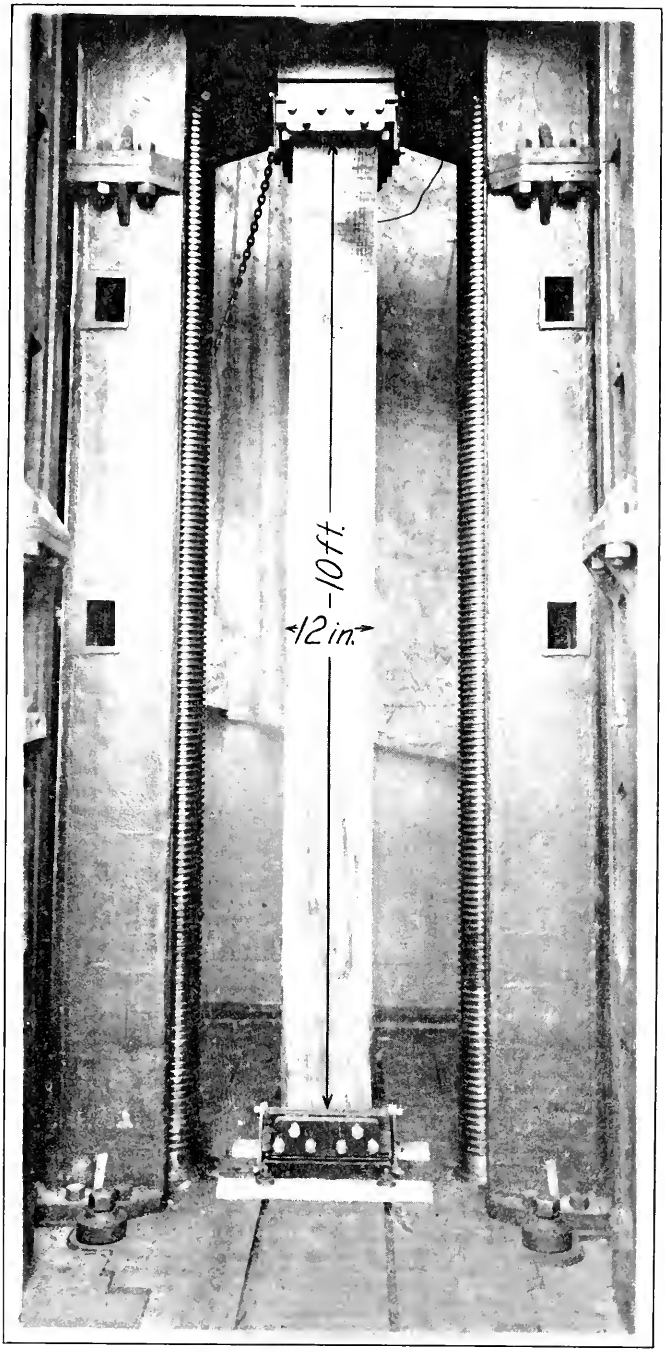
- Two clear columns 2 by 2 by 48 inches, tested under flat-ended conditions; 2 of the same size, tested under pin-ended conditions.
- Two specific-gravity determinations.
- One radial-shrinkage determination.
- One tangential-shrinkage determination.
- Four static-bending tests.
- Two impact-bending tests.
- Six compression-parallel tests.
- Two compression-perpendicular tests.
- Two hardness measurements.
- Four shear tests (2 radial and 2 tangential).
- Four cleavage tests (2 radial and 2 tangential).
- Four tension tests (2 radial and 2 tangential).
- Four toughness tests.

The results of only a part of these minor tests were required in the present study of large columns, the remaining data being utilized in other investigations of Douglas fir and southern yellow pine.

All minor tests were conducted according to standard laboratory practice (2). The rate of application of the load for the 2 by 2 by 48 inch columns was 0.04 inch per minute.

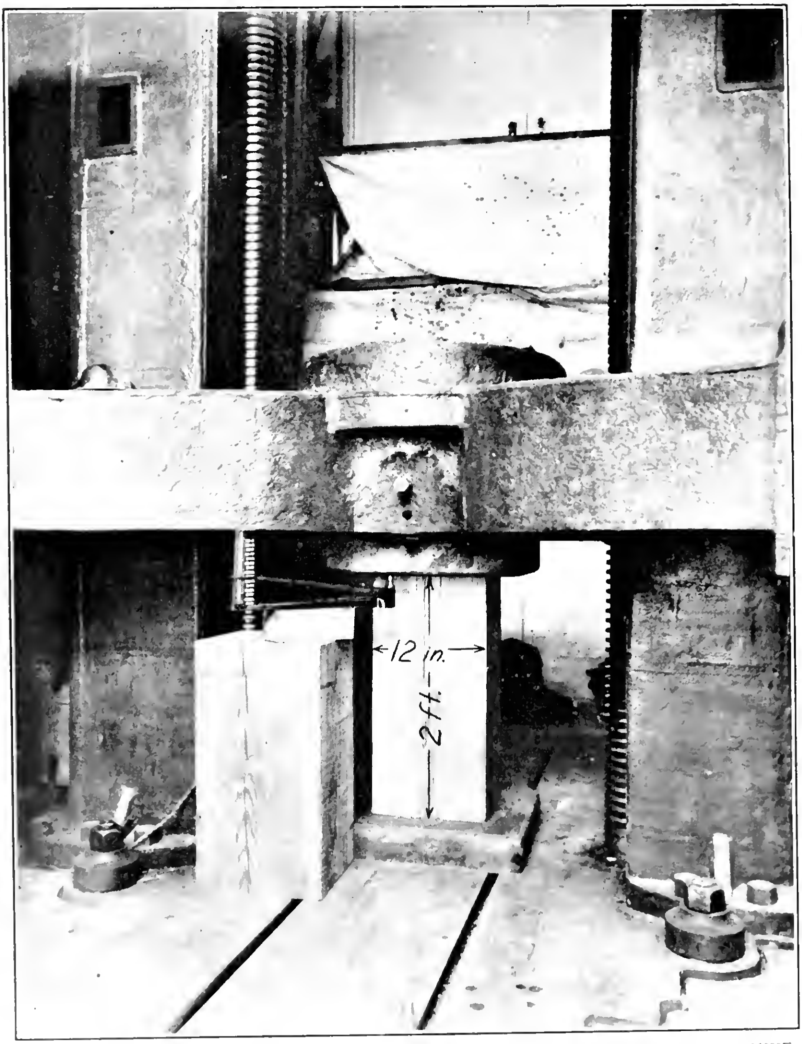
MOISTURE CONTENT DETERMINATIONS

A 1-inch thick section was cut from each of the intermediate and the 2-foot columns after the completion of the test and a total moisture determination made. Two moisture sections were cut from the long column. (Pl. 1.) A



M882F

An intermediate column in the Forest Products Laboratory 1,000,000-pound timber-testing machine



M883F

A 2-foot column in place ready for testing in the Forest Products Laboratory 1,000,000-pound timber-testing machine

TABLE 9.—*Percentage moisture distribution in 12 by 12 by 1 inch sections cut from Douglas fir structural timbers*

Green										Air-dry									
Column No.	Sectional No.[1]—									Column No.	Sectional No.[1]—								
	1	2	3	4	5	6	7	8	9		1	2	3	4	5	6	7	8	9
1	28.9	27.5	27.6	28.5	32.5	31.4	31.4	32.1	31.5	2	15.0	16.0	15.0	15.1	17.6	19.0	18.3	18.1	19.8
3	25.1	20.3	23.6	26.9	30.1	30.1	30.4	30.1	32.6	7	14.7	15.6	14.8	15.7	19.0	19.0	17.9	19.4	18.5
4	27.3	27.9	28.4	27.7	33.0	33.2	33.4	33.1	35.0	8	15.7	16.9	15.7	15.9	18.5	18.6	18.6	17.5	19.6
5	23.5	26.4	26.5	25.2	30.5	32.1	32.3	31.5	34.5	9	15.0	17.1	14.8	17.6	17.8	16.7	18.2	18.3	18.9
6	29.2	25.5	25.5	27.2	31.9	32.4	31.2	34.1	34.5	10	15.6	15.3	15.0	15.4	17.4	18.3	17.0	18.1	18.6
12	25.3	27.0	24.7	25.4	32.2	33.7	32.7	32.4	34.7	11	16.0	16.9	15.4	16.5	19.8	18.8	19.6	17.7	20.2
13	28.6	28.5	30.9	32.5	34.2	34.2	32.7	36.0	35.8	14	16.0	15.8	15.7	16.6	19.4	19.0	19.7	20.0	21.4
15	31.0	30.0	26.0	26.5	36.0	37.4	34.0	35.5	36.9	16	15.3	15.7	15.7	15.8	18.6	18.1	18.8	18.7	20.5
17	36.9	29.0	63.3	30.5	38.0	39.3	34.5	35.5	37.0	18	17.0	16.7	16.3	16.6	19.7	19.1	19.3	19.0	21.6
19	28.9	27.0	28.0	31.1	31.0	32.0	34.0	36.5	36.9	20	15.1	16.3	14.9	15.3	18.3	18.9	18.0	18.4	20.2
21	23.5	27.0	34.8	33.0	32.7	36.6	42.4	39.6	42.2	22	15.4	15.9	15.9	15.7	17.9	18.3	17.8	18.0	19.9
23	27.4	26.0	25.1	25.6	33.0	29.7	30.7	32.1	33.4	24	15.7	16.2	15.8	14.8	17.8	18.7	17.4	17.9	19.4
25	29.1	30.5	30.8	28.6	36.5	43.0	39.4	34.0	41.5	26	14.6	15.4	14.3	14.8	18.0	18.0	18.2	18.5	19.4
27	24.4	25.0	23.5	27.5	31.5	34.4	34.0	32.5	36.0	28	14.6	15.4	14.6	15.2	18.3	18.3	18.3	17.4	19.7
29	27.3	29.4	23.6	24.4	33.9	35.1	32.4	31.0	34.5	30	16.6	16.1	16.0	16.6	18.5	17.7	18.1	18.4	19.5
31	24.4	28.0	21.5	24.6	31.6	32.9	32.1	31.0	34.2	32	16.2	17.1	17.2	17.0	18.4	19.5	19.6	19.1	18.7
33	22.0	22.6	22.9	20.9	29.5	30.5	29.0	29.5	32.2	34	15.3	15.1	15.1	15.5	18.0	18.1	17.6	17.9	19.8
35	22.6	27.2	24.9	22.5	30.1	31.1	30.1	30.5	34.0	36	16.2	16.0	15.6	16.0	18.3	18.3	18.2	18.3	20.5
37	28.8	27.7	31.5	31.5	35.2	36.0	33.2	33.4	35.4	38	16.5	15.1	16.4	16.6	18.5	18.8	19.0	19.4	20.8
39	20.0	20.1	22.5	30.0	29.4	28.0	32.0	36.0	35.5	40	15.7	16.1	15.5	14.9	19.0	18.9	18.4	14.9	20.8
41	28.2	27.2	27.1	27.2	32.1	32.3	32.8	34.5	33.1	61	14.3	14.7	15.2	14.9	17.6	18.1	17.9	18.8	20.1
42	28.4	29.2	26.1	28.6	31.5	34.3	32.5	32.7	34.0	62	16.2	15.1	14.8	16.5	19.1	18.6	18.8	19.6	20.6
43	25.4	26.4	15.0	25.7	31.2	30.7	30.0	31.4	33.1	63	14.1	15.2	15.2	15.3	18.7	18.8	18.2	19.5	21.1
44	27.0	27.5	27.6	25.4	30.5	32.4	32.4	31.8	33.4	64	16.1	16.2	16.1	17.0	19.6	18.1	18.5	19.7	20.0
45	26.7	27.7	25.1	27.7	32.0	33.7	33.1	33.5	34.1	65	14.8	16.8	17.0	17.1	18.9	19.1	19.2	19.4	21.1
46	25.7	27.2	24.0	28.4	30.4	31.4	31.1	33.1	34.3	66	15.4	14.9	14.5	15.6	18.7	18.6	18.2	19.1	21.2
47	26.5	27.5	26.1	29.5	31.6	31.5	31.5	33.0	32.7	67	16.1	16.8	16.7	17.0	18.9	19.5	19.0	19.6	21.1
48	24.1	28.2	26.1	28.0	29.6	32.8	31.0	32.2	34.4	68	15.9	16.2	15.6	17.1	18.9	18.8	18.3	19.7	20.3
49	29.2	32.6	26.8	33.5	32.6	34.4	32.1	36.5	35.4	69	15.6	16.6	15.9	16.2	18.9	19.5	18.9	19.5	20.6
50	33.3	37.7	28.5	34.0	36.9	40.3	38.4	39.2	38.9	70	16.4	15.1	15.4	16.9	19.0	18.6	18.9	19.1	20.6
51	24.5	31.0	29.9	28.0	34.4	37.3	35.6	33.1	37.6	71	16.0	16.4	16.2	17.4	18.9	20.5	20.0	20.5	21.8
52	27.1	30.0	29.1	31.1	34.0	34.9	35.4	35.5	35.5	72	15.7	15.9	15.1	16.1	18.7	18.6	18.5	18.7	20.9
53	25.5	34.0	28.4	26.9	35.6	40.1	42.1	37.1	37.4	73	14.9	15.5	14.2	14.2	18.1	18.1	17.3	18.1	20.3
54	27.5	36.1	29.1	29.4	35.4	41.9	41.0	39.1	39.9	74	17.6	16.9	15.9	17.5	20.4	20.0	19.5	20.1	23.5
55	30.5	34.8	32.4	28.5	44.0	45.4	46.8	44.0	49.4	75	15.7	15.2	14.9	16.4	20.1	19.1	19.0	20.6	22.7
56	26.5	26.5	25.9	26.3	32.1	32.9	30.4	35.0	38.6	76	15.9	16.0	15.6	16.6	18.6	19.6	19.1	19.8	21.9
57	20.1	27.9	24.0	26.5	31.0	34.6	31.8	32.0	36.5	77	14.0	15.0	15.0	15.9	18.0	17.7	18.2	18.6	20.2
58	25.9	30.3	24.2	25.4	32.1	33.5	29.0	30.9	33.7	78	14.9	14.6	15.1	16.4	18.2	17.3	18.0	18.6	20.1
59	26.0	26.0	24.0	27.5	29.9	29.0	29.5	29.6	31.0	79	16.9	16.9	16.1	15.5	20.1	19.6	20.1	17.9	21.5
60	23.2	23.7	22.4	25.1	28.6	28.3	27.3	29.0	31.1	80	16.9	16.0	16.6	16.5	18.7	19.5	20.1	18.9	21.6

[1] Sectional numbers correspond to the standard sections of Figure 7.

TABLE 10.—*Percentage moisture distribution in 12 by 12 by 1 inch sections cut from southern yellow pine structural timbers*

Column No.	Green									Column No.	Air-dry								
	Sectional No.[1]—										Sectional No.[1]—								
	1	2	3	4	5	6	7	8	9		1	2	3	4	5	6	7	8	9
1	13.0	41.2	66.3	79.5	50.4	40.7	57.0	93.9	61.1	11	14.4	14.7	14.5	13.9	17.6	17.5	16.6	16.8	19.0
2	25.6	22.8	19.4	21.6	29.4	30.1	26.8	29.0	28.6	12	15.3	16.2	16.8	16.4	17.5	18.2	17.5	18.7	20.4
3	24.1	24.9	22.6	22.6	33.3	34.6	31.3	39.8	39.8	13	16.4	15.5	15.8	15.4	18.4	17.5	17.9	18.5	20.1
4	54.1	57.9	31.1	72.5	58.6	45.0	30.9	58.1	37.8	14	14.7	14.5	14.4	14.0	16.0	16.3	16.0	15.5	17.1
5	29.3	29.2	28.1	23.3	29.4	30.5	28.9	24.9	29.6	15	14.9	15.0	15.8	15.2	18.0	18.5	18.8	18.8	21.2
6	26.3	35.6	55.8	30.1	30.1	31.2	41.0	31.4	32.1	16	15.5	19.0	18.0	15.0	18.6	20.5	19.4	20.0	24.0
7	26.8	22.6	23.8	23.1	27.8	28.1	27.8	28.1	28.8	17	16.4	16.2	16.4	16.5	18.1	18.4	19.0	18.1	19.8
8	31.3	30.5	25.8	32.6	32.0	36.5	37.4	35.3	35.0	18	16.1	15.8	15.9	15.5	18.0	17.4	18.1	18.1	19.1
9	29.9	24.5	36.0	47.1	29.1	27.8	31.4	30.6	31.3	19	16.9	16.4	16.0	16.8	19.2	19.1	18.6	19.0	20.8
10	24.7	31.1	29.7	24.9	29.3	33.1	32.3	31.8	31.9	20	14.9	16.1	15.0	14.9	16.9	14.8	15.1	14.6	18.4
21	23.6	24.3	21.9	23.6	28.2	30.5	28.1	27.3	30.6	31	16.3	16.6	17.0	17.0	17.5	18.0	17.4	19.0	19.2
22	27.0	25.0	29.5	29.5	28.3	30.1	31.8	30.9	31.1	32	17.9	17.1	17.1	17.6	18.7	20.9	20.7	20.4	22.5
23	22.1	20.9	21.1	21.1	25.5	23.9	26.5	30.0	29.8	33	17.0	15.8	17.0	17.8	18.8	17.8	18.0	19.4	20.5
24	30.4	25.9	37.9	32.9	36.7	35.1	42.6	41.8	41.9	34	16.6	16.5	15.8	16.5	18.2	18.5	18.0	18.4	20.7
25	33.1	36.4	30.3	30.0	39.5	42.4	37.9	33.6	41.8	35	15.4	15.8	15.2	15.3	16.8	16.8	17.0	17.0	18.4
26	38.8	30.8	24.5	27.7	20.7	27.9	27.4	29.1	29.0	36	15.9	16.3	15.8	16.4	18.9	18.5	16.8	19.5	21.1
27	109.8	51.4	26.6	62.6	111.8	37.7	28.5	50.8	37.2	37	16.9	16.5	15.3	15.4	19.1	19.8	17.8	18.9	20.5
28	62.9	30.2	52.5	68.1	54.8	33.5	43.5	100.2	37.2	38	15.2	14.6	16.3	14.8	19.1	17.7	18.3	17.5	26.2
29	29.3	22.9	31.8	29.0	33.5	36.9	31.8	32.2	36.7	39	15.0	15.6	16.4	15.3	17.3	18.5	20.1	17.4	20.0
30	21.0	25.0	30.0	22.2	27.2	30.2	31.8	25.2	32.3	40	15.7	16.1	15.0	15.1	18.3	18.5	19.0	17.1	21.2
41	41.0	42.5	16.0	28.9	33.6	35.0	35.2	30.2	33.1	51	17.0	17.1	16.4	17.5	19.5	18.9	19.9	20.4	21.2
42	28.5	21.1	51.7	59.1	30.8	32.0	41.5	32.5	31.5	52	16.1	16.6	16.1	16.2	17.7	19.4	18.6	18.6	19.5
43	33.4	30.2	26.3	27.8	33.5	36.5	37.1	32.7	43.5	53	15.5	16.0	16.3	16.0	19.8	20.3	19.4	19.2	20.6
44	28.1	27.1	37.9	40.5	30.4	31.2	32.8	34.0	31.6	54	16.0	16.0	15.9	16.7	19.4	19.3	20.5	20.2	20.9
45	28.9	27.4	30.3	31.9	33.8	35.1	31.3	36.4	36.1	55	17.0	18.4	17.5	17.9	21.1	22.3	20.7	22.3	22.2
46	40.4	37.5	36.5	33.0	38.0	36.3	36.5	38.4	36.0	56	16.1	15.3	15.4	16.0	20.0	19.4	18.4	20.0	21.4
47	29.5	28.6	28.5	31.6	28.4	39.6	31.9	36.6	34.1	57	16.6	17.3	17.0	18.1	20.5	20.9	20.9	20.9	22.4
48	21.6	27.2	21.4	24.0	29.0	32.1	29.4	43.3	29.4	58	18.0	17.5	17.0	17.6	23.9	21.0	21.9	21.3	23.7
49	26.2	31.1	54.5	34.6	31.8	34.0	33.9	32.4	34.4	59	16.6	18.4	17.8	16.8	20.0	22.0	22.0	21.5	20.8
50	59.9	42.7	42.1	45.6	39.5	35.7	34.0	33.8	32.2	60	15.3	16.6	17.1	17.3	22.6	21.0	20.4	22.6	21.8
61	21.6	29.8	26.4	30.3	32.0	33.5	31.5	39.6	28.2	71	15.8	16.2	16.0	15.5	18.6	18.8	19.1	19.5	20.4
62	26.7	28.3	28.5	28.0	32.7	32.0	33.7	31.5	31.0	72	15.9	17.4	16.5	16.5	19.4	19.1	19.4	20.3	20.5
63	33.5	35.3	34.0	29.6	33.8	32.3	34.4	34.3	31.4	73	17.2	18.1	25.0	17.5	19.0	21.2	18.4	29.5	20.0
64	28.2	33.5	30.2	32.1	41.5	41.6	38.7	41.5	40.3	74	15.2	15.6	16.0	15.8	19.3	18.9	19.5	19.5	20.4
65	83.9	52.5	68.8	92.0	48.4	35.5	39.5	38.3	35.0	75	16.2	17.0	15.3	16.1	20.6	19.9	19.3	20.0	20.0
66	31.4	37.2	45.4	33.2	35.1	36.0	37.6	37.5	35.5	76	15.2	16.2	16.5	16.0	19.4	20.4	18.7	19.8	20.2
67	27.8	32.6	37.9	26.4	34.5	34.0	35.8	33.8	33.3	77	17.5	17.7	16.3	17.6	20.9	21.2	19.9	21.5	20.9
68	37.5	28.0	30.1	37.0	39.0	35.6	33.0	36.5	35.0	78	17.0	17.6	17.2	16.5	20.5	20.7	19.3	20.0	22.2
69	26.1	30.3	30.9	32.7	33.4	36.2	36.9	37.3	38.5	79	15.3	17.4	15.5	16.6	18.8	21.2	18.7	20.7	20.2
70	25.6	29.5	41.0	29.6	28.5	30.8	30.0	31.1	31.6	80	18.0	17.2	16.8	17.5	19.9	19.3	18.7	19.9	21.0

[1] Sectional numbers correspond to the standard sections of Figure 7.

total moisture determination was made upon one section of each pair and a moisture distribution determination was made on the other. A position diagram of the standard moisture-distribution specimen is shown in Figure 7 by means of which corresponding positions for the specimens given in Tables 9 and 10 may be ascertained. All moisture determinations were made according to standard laboratory practice (*1*).

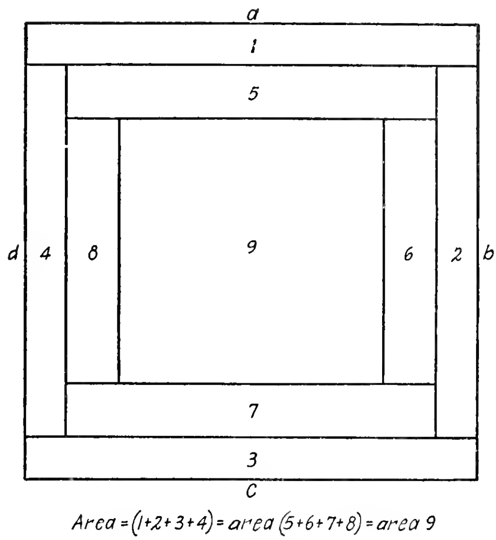


FIGURE 7.—Standard position diagram for moisture-distribution determinations

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TECHNICAL BULLETIN No. 166 MARCH, 1930

TIMBER GROWING AND LOGGING PRACTICE IN THE NORTHEAST

MEASURES NECESSARY TO KEEP FOREST LAND PRODUCTIVE AND TO PRODUCE FULL TIMBER CROPS

BY

SAMUEL T. DANA

Formerly Director, Northeastern Forest Experiment Station
Forest Service

INTRODUCTION BY

WILLIAM B. GREELEY

Formerly Forester, Forest Service

UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D. C.

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TECHNICAL BULLETIN No. 166 — MARCH, 1930

UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

TIMBER GROWING AND LOGGING PRACTICE IN THE NORTHEAST [1]

By SAMUEL T. DANA, formerly *Director, Northeastern Forest Experiment Station*,[2] with Introduction by WILLIAM B. GREELEY, formerly *Forester, Forest Service*

CONTENTS

INTRODUCTION

Forestry in the United States is no longer merely a theory or a subject for discussion: it has gotten down to concrete things in the woods. Nor is the growing of timber confined to public lands; it is gradually making headway on land in private ownership. It is becoming an art of land management, expressed in practical measures for protecting forest growth from fire and other destructive agencies, for logging timber so as to produce a new crop of wood, and for planting forest trees on cut-over areas. The value of timber, along with other economic considerations, is causing landowners more and more widely to study the possibility of profitable reforestation. These developments have created a general demand for information on the timber-growing methods which are adapted to the various types of forest growth in the United States, and on what these methods will cost.

Timber culture, like the growing of farm crops, is necessarily governed in any country by the soil and climate, by the requirements

[1] This bulletin is based in large part on field studies and manuscript reports by R. C. Staebner, forest inspector, and Raphael Zon, director, Lake States Forest Experiment Station. Acknowledgment is also made of the hearty cooperation received from representatives of forest schools and State forestry departments, timberland owners, and many others.

[2] The Northeastern Forest Experiment Station is maintained at Amherst, Mass., in cooperation with the Massachusetts Agricultural College.

of the native forest trees, and by the national economic circumstances. Lessons may be drawn from the experience of other countries, as the United States has drawn upon the forestry practice of Europe, but profitable methods of growing timber, particularly under the wide range of forest types and economic conditions in the United States, can be evolved only from our own experience and investigation, region by region. Hence, to meet the demand for information on practical ways and means of growing timber profitably in the various parts of the United States, it is important that the results of of our own experience and investigation to date be brought together and set forth in the clearest possible way.

This the Forest Service has attempted to do in a series of publications dealing with the 12 principal forest regions of the United States. The information presented has been gathered from many different sources, including the experience, as far as it was obtainable, of landowners who have engaged in reforestation. An effort has been made to bring together all that any agency has yet learned or demonstrated about the growing of timber in the United States; and the results have been verified as far as possible by consultation with the forest industries, State foresters, and forest schools. These publications thus undertake to set forth, in a simple form, what are believed to be the soundest methods of reforestation as yet developed in our common experience and study in the United States.

Necessarily, the Forest Service claims no finality for the measures proposed. Timber growing in every country has come about through a gradual evolution in industrial methods and the use of land. All too little is yet known of the best methods of growing timber under American conditions. As time goes on, research and practical experience will add greatly to the success and certainty of the measures carried out in our woods; just as American agriculture has steadily become more highly developed or just as our manufacturing processes have been perfected through experience and study. But we know enough about growing timber now in the forest regions of the United States to go right ahead. Believing that the forest landowners of the United States are now ready to engage in timber growing on a large scale, the Forest Service has endeavored to place before them in concise terms the best suggestions and guides which the experience of this country to date affords.

In these publications the measures proposed for a particular forest region have been arranged in two general groups. The first includes the first steps, or the minimum measures based on local physical conditions, that are needed to prevent timber-bearing lands from becoming barren. These measures, in which the prevention of fire is of outstanding importance, represent broadly speaking the least that must be done and the lowest cost that must be incurred to keep forest lands reasonably productive. While influenced in some cases by the economic conditions in the region, they have been worked out primarily from the standpoint of the landowner who may not be ready to engage in real timber culture but who wishes to prevent cut-over tracts unsuitable for any purpose except timber growing from becoming a liability on his hands. Except within certain limitations, which are discussed in dealing with particular regions, the Forest Service believes that these first steps or minimum measures should be speedily applied to all of the forest lands in the United States, and that public policy should encourage their universal application in such ways as protection from fire and the adjustment of forest taxation to the business of timber growing.

The second group of proposed measures constitutes what may be called the desirable forestry practice in the region concerned as far as our knowledge and experience to date enable us to determine it. These measures are designed to grow reasonably complete crops of the more valuable timber trees, making full use of the real productive capacity of the land. The recommendations are addressed primarily to the landowner who wishes to use his property up to its full earning power for timber culture. It is impossible to frame any general set of measures of this character that are adapted to the individual needs of particular holdings or industrial establishments. This is true particularly of forest regions like the Northeastern States, which include a great variety of local situations both in the types of growth and in economic circumstances. Hence, in presenting this group of suggested measures, the Forest Service has attempted only to draw the broad outlines of the more general and fundamental things, with illustrative methods of forest practice. The details of intensive forestry, like the details of intensive agriculture or engineering, call for expert survey in working out the plans and methods best adapted to a particular tract of land or a particular business. One of the most important features of expert planning for the management of a particular forest property is to devise not only woods operations that will produce full crops of timber but also a scheme of logging that will afford a continuous yield of products desired, in order that sustained earnings may be realized or a sustained supply of raw material made available.

In some cases it is not practicable to draw a hard and fast line between the first steps that will maintain some degree of productiveness on forest land and the most intensive measures that will bring the quantity and quality of wood produced up more nearly to an ideal management. Gradations between the two general groups of measures are inevitable. The Forest Service has not attempted, therefore, to deal with the two general types of forest practice as wholly separate and distinct, but has rather endeavored to present a commonsense and practical résumé of the various steps in timber growing in the form that will be most helpful to the man in the woods. The bulletins have been written for the landowner and the lumberman rather than for the technical forester. Their purpose is to put the main ideas into such form as, in view of the specific needs and problems of each region, will be most useful to the man to whom timber growing is a concrete business and logging problem. At the same time it is hoped that they will have value for the everyday reader who is interested in forestry as an important phase of land use in the United States and in the public policies designed to bring forestry about.

It is impossible for publications necessarily dealing in broad terms with the conditions existing over large regions to attempt any brass-tack conclusions on the cost and returns of timber growing. The approximate cost of the measures advocated is indicated as far as practicable and the extent to which they may be of benefit in connection with logging operations, but no attempt is made to segregate the items chargeable to harvesting one crop of timber from those which should be regarded as invested in a following crop. Conservative estimates of the future yields of timber that may be expected under the various practices recommended are given where the facts available appear to warrant them; but no forecasts of the profits to be derived from commercial reforestation are attempted. The financial aspects of forestry can not be dealt with in general terms. Here again expert advice must deal with the situation and with the problems of the individual forest owner or manufacturer.

As a broad conclusion, however, with the exception of limited situations which are dealt with region by region, the Forest Service has tremendous faith in the commercial promise of timber growing to American landowners. The law of supply and demand is working steadily to create timber values which in large portions of the United States will pay fair returns on forestry as a business. The economic history of other countries which have passed through a cycle of virgin-forest depletion similar to that which the United States is now traversing points to the same inevitable conclusion. The time is fast approaching when forestry, and forestry alone, will supply the enormous quantities of wood demanded by American markets. The fundamental laws of business must in the nature of things so operate as to enable the markets of forest products to be supplied at a profit to the grower of timber. The returns already being obtained from this form of land employment at many points in the eastern United States show plainly enough that this relationship between the value of timber and the cost of producing it is already coming about to a marked degree.

To the men who own forest-producing land in the United States, or are engaged in industries which require raw material, forestry now offers a commercial opportunity. Satisfactory returns from forestry can not be promised in sweeping terms any more than returns from the manufacture of lumber or paper. But the opportunity for a profitable employment of capital and business talent in the growing of timber merits the same consideration and the same expert guidance as industrial opportunities in the conversion of timber. This applies with special force to the commercial institutions in the United States which have made large capital investments in manufacturing plants and distributing organizations, dependent for their maintenance upon a future supply of forest-grown material. It applies equally to the owners of land in large tracts or farm wood lots, the earning capacity of which lies solely in the growing of trees, and which without tree growth will become either a doubtful asset or an outright liability.

The Forest Service earnestly asks the forest landowners of the United States to determine for themselves, with the same care with which they would approach any other business problem, whether timber growing does not offer a commercial opportunity which should be grasped. It commends this series of publications to them, not as a complete or authoritative scheme that can forthwith be followed with profit in their own woods, but as a starting point in utilizing the opportunities that forestry may hold out.

 W. B. Greeley.

THE FORESTS OF THE NORTHEAST

FOREST AREAS

The "Northeast," as the term is used in this bulletin, includes the six new England and the three Middle Atlantic States. Practically all of this territory was originally covered with forests, somewhat more than half of which were gradually cleared away in the course of agricultural development. Since the Civil War, however, and more particularly since 1880, there has been a steady reversion of the poorer farm lands to forest. In the 40 years from 1880 to 1920 the area of improved farm land decreased 30 per cent, and the process still continues. The decrease has ranged from a minimum of 12 per cent in Pennsylvania to a maximum of 70 per cent in New Hampshire. (Fig. 1.) Nearly all of this land is, or will be sooner or later, restocked with trees.

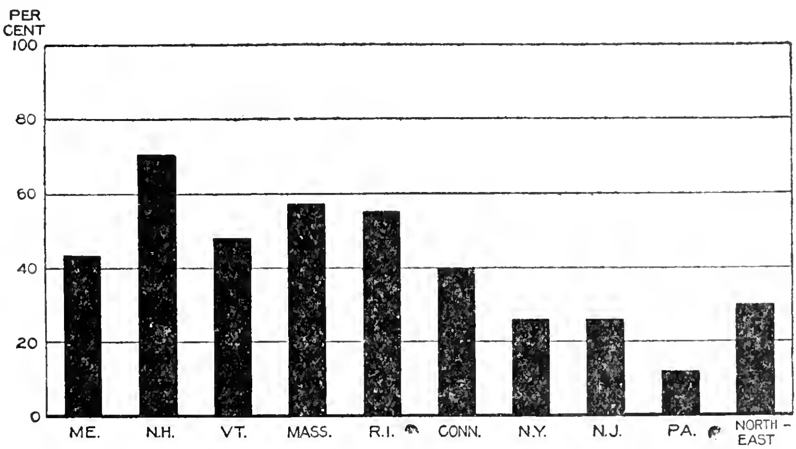


FIGURE 1.—Decrease in the acreage of improved farm land in the Northeast, 1880–1920. (Figures from United States census reports)

The present forest areas in the Northeast, as estimated by the respective State foresters, are given in Table 1. These areas can be expected to increase with the continued abandonment of farm lands.

TABLE 1.—*Forest areas in the Northeast, by States, 1927*

State	Forest area	Ratio of forest area to total land area of State	State	Forest area	Ratio of forest area to total land area of State
	Acres	*Per cent*		*Acres*	*Per cent*
Maine	15,000,000	78	New York	12,100,000	40
New Hampshire	4,400,000	76	New Jersey	2,100,000	44
Vermont	3,800,000	65	Pennsylvania	13,000,000	45
Massachusetts	3,300,000	64			
Rhode Island	300,000	44	Total	55,500,000	53
Connecticut	1,500,000	49			

The Northeast is the most densely populated and at the same time one of the most extensively forested regions in the United States. Although embracing only 5 per cent of the total land area of the country, it includes 28 per cent of the population and 12 per cent of the forest area. (Pl. 1.) The population is chiefly urban and industrial in character, the 24 per cent that is rural constituting the smallest percentage for this class in any group of States in the country.

More than 50 per cent of the region as a whole, and more than 70 per cent of New England, is forest land, as against 25 per cent for the entire country. Extensive areas of forest are found throughout the region, and not only in the so-called "wild-land" sections. Even in so densely populated a State as Massachusetts, there are towns within 50 miles of Worcester that have 90 per cent of their area in forest. Because of the relatively small agricultural development of the region as a whole, farm wood lots constitute only 28 per cent of the total forest area. They are, however, an important part of most farms, particularly in New England, where their total area is greater than that of improved land. In addition, there is a considerable area on farms classed as "other unimproved land," much of which is doubtless already bearing an inferior tree growth or is capable of being used for forest production.

The relations between forest land, improved farm land, and other land (towns, roads, barren mountain tops, salt marshes, etc.) are shown by States in Figure 2. The farm wood lots are of relatively greater importance from the standpoint of forest management than their actual area would indicate. Their usual occurrence in relatively small tracts reduces the danger from fire, and proximity to good markets permits them to be handled by more intensive methods than can be employed in the more remote sections.

The large proportion of forest land, as well as the market for forest products offered by the dense population and the high industrial development, points to timber growing as an essential factor in the prosperity of the region.

FOREST REGIONS AND TYPES

The Northeast includes five distinct forest regions. These are shown roughly on the accompanying map. (Fig. 3.) Since changes in region are due to broad changes in climate, the actual boundaries are not, of course, so sharp as those indicated. Instead, adjacent regions are always separated by transition zones of varying width in which trees characteristic of both regions are common. Altitude as well as latitude has a marked influence on climate and therefore on the character of the forest. In the mountains well to the south, for example, such typically northern trees as spruce and yellow birch are found.

Forest regions are divided into forest types, each of which consists of a characteristic combination of species. Changes in type are due to minor differences in climate and still more to soil differences. For this reason the boundaries between forest types are much more distinct than those between forest regions. In the Northeast the varied topography and the glacial soils characteristic of the bulk of the territory give rise to frequent changes in the composition of the forest, so that several types may occur in an area of a few square miles. It would therefore be impossible to show accurately the distribution of types in the different forest regions except on a very large scale map, even if the detailed information necessary for this were available.

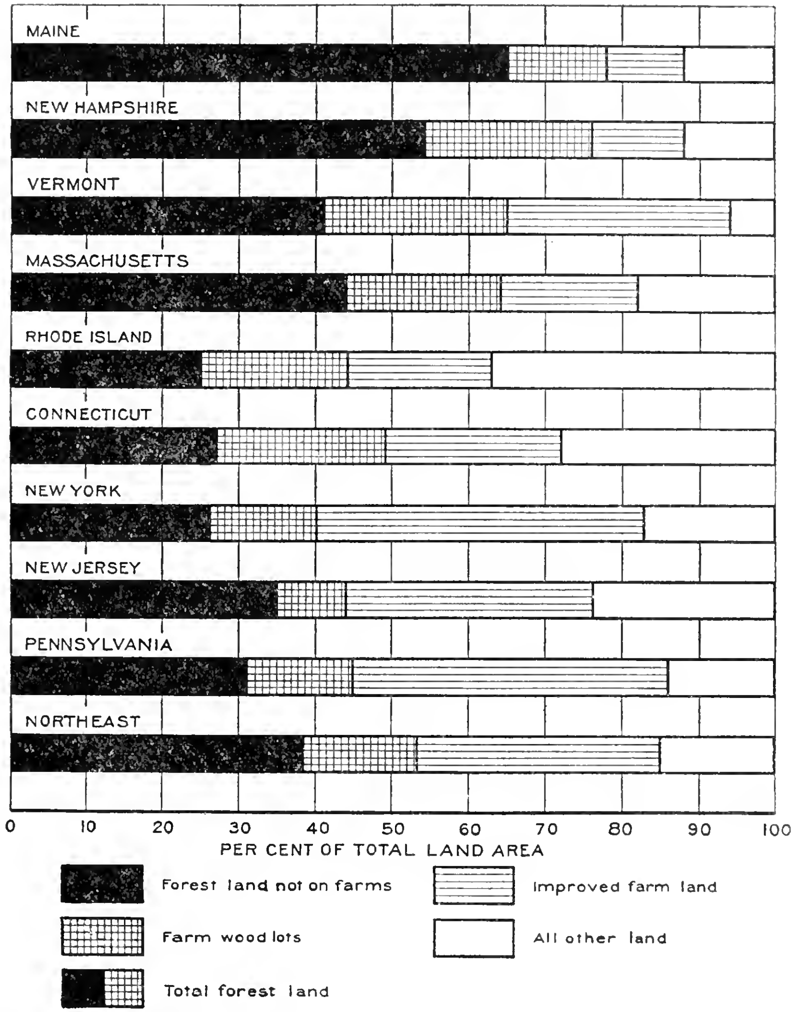


FIGURE 2.—Forest land, improved farm land, and other land in the Northeast, by States, in percentages of total land area

Forest types in turn may be subdivided into any number of stands, which are simply aggregations of trees growing on a limited area with substantial uniformity not only in composition, but in age, distribution, density, and site. For really intensive forest management the stand is the unit of treatment.

In this bulletin it will obviously be impossible to suggest methods for the handling of individual stands, or even of all the 30-odd forest types which are now recognized by foresters in the Northeast (*3*, *38*, *39*)[3]. Many of these types are of minor importance, and the differences between closely related types are often small. Attention will therefore be concentrated on those of major importance from the standpoint either of commercial value or of area covered.

The recommendations made are based as far as possible on the experience of timberland owners in the actual management of their forest lands. Comparatively little, however, has so far been done in many forest types, and on few areas have accurate records been kept of the operations performed, the costs involved, and the results obtained. Definite figures as to what may be expected from a given

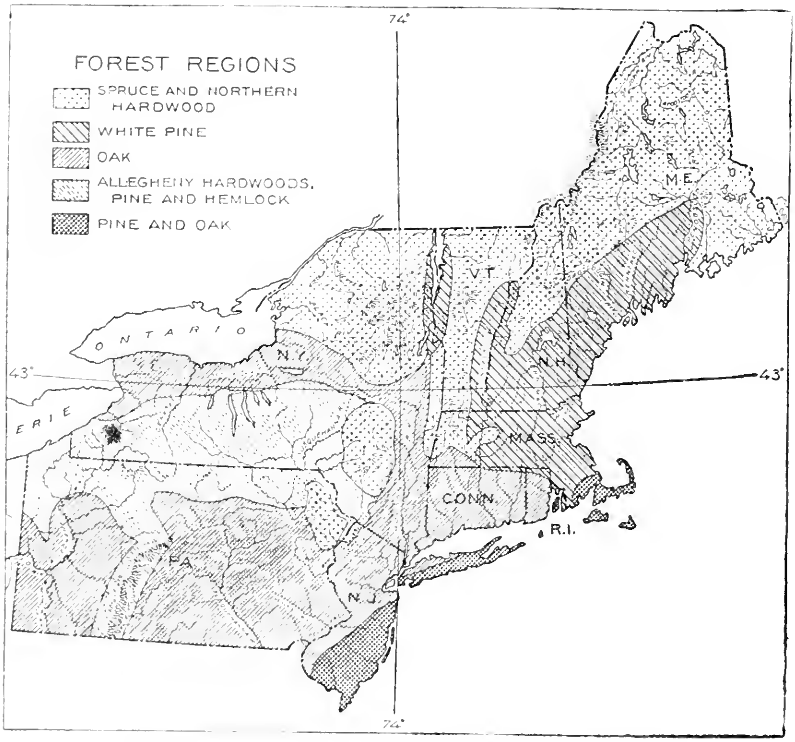
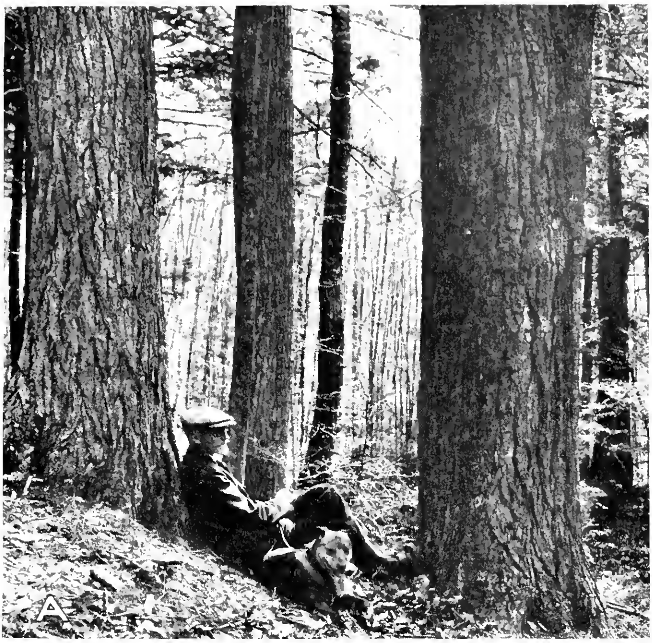


FIGURE 3.—Forest regions of the northeastern United States

treatment can not, therefore, be given so often as might be anticipated in a part of the country where so much attention has been paid to forestry as in the Northeast. Moreover, in dealing comprehensively with so large and varied a forest area the recommendations are necessarily somewhat general in character, whereas silviculture is essentially local. They should, therefore, be looked upon more as a guide than as definite instructions, and should often be modified when applied to specific tracts.

More specific information and advice on the handling of forest lands can be obtained from State foresters, extension foresters, and

[3] Italic numbers in parentheses refer to "Literature cited," p. 116.



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VETERAN WHITE PINE STANDS IN MASSACHUSETTS

These two stands in the Harvard Forest at Petersham represent typical pure pine (A), and mixed white pine and hardwoods virgin growth (B) of the white pine region.

F-4787 F-5531

A, Variation of type with altitude. A typical view in the spruce and northern hardwoods region of the Adirondack Mountains, showing the northern hardwoods type at the medium elevations and the spruce-slope type at the upper elevations. B, a skidway of spruce logs in Hamilton County, N. Y., piled ready for hauling.

consulting foresters. The names and addresses of these men will gladly be furnished by the Forest Service on request.

FOREST UTILIZATION AND LOGGING PRACTICE

The forests of the Northeast have been subjected to almost continuous cutting since 1623, when the first sawmills were erected. In 1840, the first year for which figures are available, 65 per cent of the lumber production of the entire country came from this region. In 1927 Maine led all other States in wood-pulp production, with New York, Pennsylvania, and New Hampshire third, fifth, and sixth, respectively. Other industries use large quantities of wood for fuel, railroad ties, posts, poles, mine timbers, turned articles, veneer, furniture, cooperage, and other products.

The forest and wood-using industries have always played an important part in the economic life of the Northeast. The forests of the region are, however, no longer able to meet the timber requirements. Maine, New Hampshire, and Vermont are now the only States in the region which still produce from their own forests as much lumber as their industries use. The other six States import from 5 to 50 times as much lumber as they cut. These imports come largely from the South and the Pacific Northwest. Clearly, the exhaustion of the virgin forests in these regions will produce a ready market for all the local timber that can be grown under better methods of forest management.

The logging practice so far followed in the utilization of both virgin and second-growth forests has had little relation to timber growing. Methods of cutting have ordinarily been chosen for their cheapness and effectiveness in getting out the logs, without particular reference to the future of the forest. Fortunately, the methods adopted have been much less destructive than those used in certain other parts of the country.

In a typical logging operation of considerable size, the trees to be removed are first felled and cut into logs (*5*). This is usually done in the fall unless peeled pulpwood is desired, making it necessary to do the felling and peeling between the latter part of May and the middle of August. The logs are next dragged on the ground or hauled on small drays to the skidways along the main sled roads. This skidding is almost always done by horses, and very seldom by mechanical power. At the arrival of deep snow, skidding ceases, and the logs are hauled on heavy sleds to the waterway, railroad, or mill. This hauling may be done by horses, steam or gasoline log haulers, or caterpillar tractors. In those parts of the region where there is not enough snow to permit the use of sleds, the hauling is done with heavy wagons or trucks.

The network of roads and trails required for a logging operation of this sort is shown in Figure 4 (*27*). The main hauling road has a cleared width of at least 20 feet, the main yarding roads of 5 or 6 feet, and the minor skid trails of 2 or 3 feet. The skid trails, however, run up to twice the width when two horses are used or when drays are substituted for snaking. On the surface covered by the roads and trails practically all the seedlings and saplings already on the ground are destroyed. The damage is particularly marked with

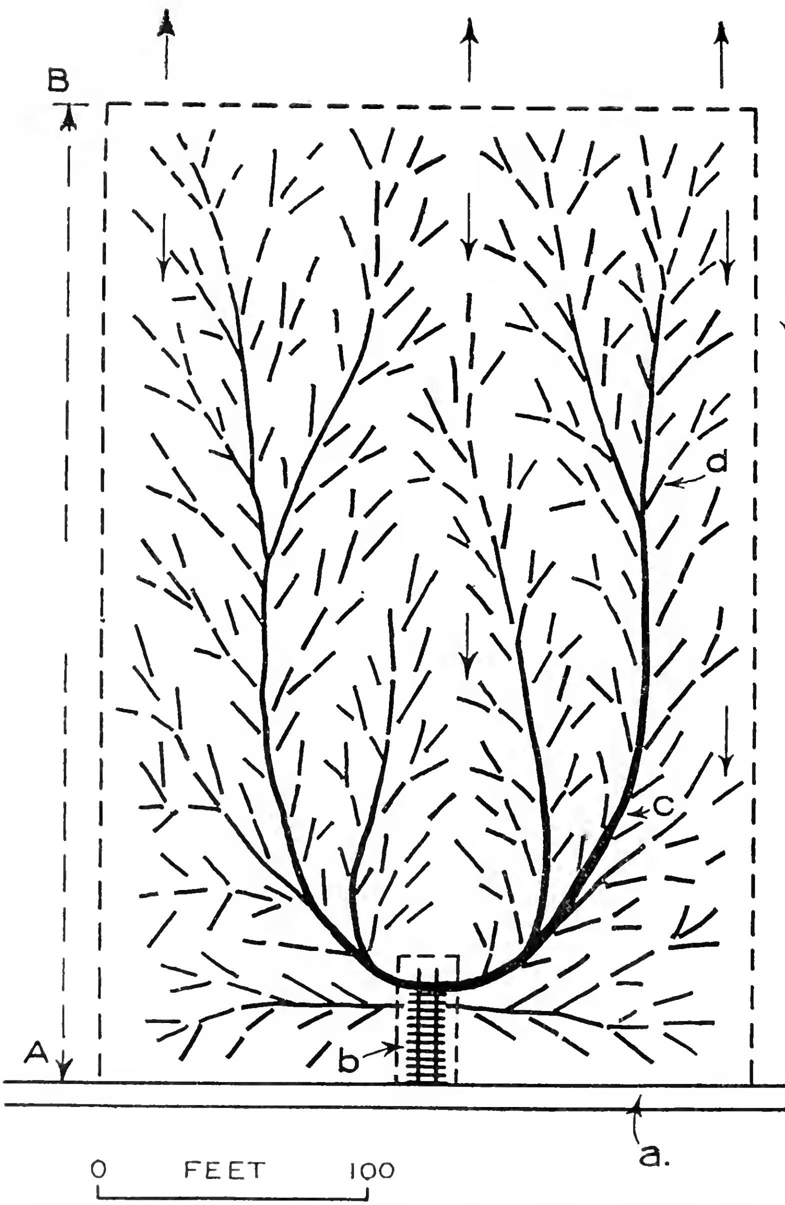

FIGURE 4.—A typical scheme of skidding-trail location, showing (*a*) main sled road, (*b*) skidway, (*c*) main skidding trail, and (*d*) secondary skidding trail. The arrows indicate the direction of the slope. (Reproduced by permission of the Yale School of Forestry.)

two-horse skidding. On the other hand, the tearing up of the soil in the skid trails probably makes a more favorable seed-bed for subsequent reproduction. The result is, therefore, not so much to denude the area as to change the composition of the forest and to set it back by the period required for the new reproduction to reach the size of the young growth destroyed.

On farm wood lots the method of logging is somewhat different. Here a portable sawmill is usually set up on the tract to be cut, and the logs are skidded or hauled directly to the mill. Each operation is limited to a few hundred thousand board feet. Except for the fact that there is no main hauling road, the system of skid trails and yarding roads is much the same as in the larger operations, and the damage to the young growth is similar.

In both types of operation, the degree of damage increases with the severity of the cutting. In what is virtually clear cutting—such as is often practiced for pulpwood, box boards, chemical wood, and fuel—the slash resulting from logging may cover as much as two-fifths of the area, the remainder of which is pretty thoroughly dissected by skid trails and roads. Such cutting has, however, become common only within the last 20 years. Up to that time, the limited market for small material made it more profitable to cull out only the larger trees, so that the entire cover was seldom removed at any one time.

On the whole, the logging practice followed in the Northeast has resulted in the deterioration rather than in the devastation of the forest. This is due largely to the fact that the climate and the soil are in general so favorable for tree growth, and the trees themselves so vigorous and aggressive, as to enable the forest to stand a good deal of abuse. It is a striking fact that where fire has been kept out, natural reproduction of some sort has ordinarily taken place; but the new stands have by no means always been well stocked or composed of desirable species. Such stands will not produce the highest yields of which the land is capable, nor will they meet the timber requirements of the region. Moreover, there are many other areas where the forest is in a deplorable condition and where its productive capacity has been greatly reduced.

Such really denuded forest land as occurs in the Northeast, and this probably aggregates several million acres, is attributable much more largely to fires than to logging. A single fire following cutting sometimes converts the burned-over area into a barren waste, and a second fire is fairly certain to do so. Some land of this sort will gradually revert through natural reproduction to forest growth of economic value, but the process will at best be slow, and in most cases planting will be necessary to restore the land to productivity within a reasonable time.

KEEPING FOREST LAND PRODUCTIVE

FIRE CONTROL

From what has already been said, it is clear that keeping forest land productive is primarily a matter of keeping out fire. Without fire control, devastation is not only possible but probable; mature timber is not safe from destruction, young growth is not likely to reach maturity, and cut-over and denuded areas have little chance to restock. (Pl. 4.) With fire control, the maintenance of some kind of tree growth on forest land is reasonably certain. Marked deterioration may still result, but real devastation is unlikely. The importance of fire control as the first and most essential step in timber growing can, therefore, hardly be overemphasized.

Although this basic fact is now generally recognized in the Northeast, Table 2 indicates that the problem of adequate protection can not yet be regarded as satisfactorily solved. The figures for damage are particularly striking in view of the fact that they do not take into account the vast amount of intangible and indirect damage resulting from forest fires, such as decay of damaged timber, replacement of desirable species by less desirable but more fire-resistant species, soil deterioration and erosion, loss of wild life, uncertain stream flow, interrupted tourist traffic, and the like. Because of different standards in the gathering of statistics the figures for the different States are not entirely comparable.

TABLE 2.—*Number of forest fires, area burned, and degree of damage in the Northeastern States, annual average, 1916–1925*

State	Fires	Forest area burned		Total damage
	Number	*Acres*	*Per cent*	*Dollars*
Maine [1]	155	23, 594	0. 16	152, 814
New Hampshire	608	4, 894	. 11	59, 805
Vermont	94	1, 229	. 03	8, 020
Massachusetts	2, 590	18, 129	. 55	157, 105
Rhode Island [1]	59	4, 800	1. 60	46, 547
Connecticut	811	26, 723	1. 78	132, 936
New York [2]	555	15, 648	. 13	29, 682
New Jersey	881	63, 910	3. 04	300, 618
Pennsylvania	2, 143	153, 821	1. 18	497, 642
Northeast	7, 896	312, 748	. 56	1, 385, 169

[1] Records not complete for entire State prior to 1920.
[2] Records apply only to the so-called fire-protection area.

FIRE-CONTROL ORGANIZATION

Active participation by the State is essential in effective forest-fire control. The efforts of any individual owner or group of owners are seriously handicapped by the fact that fire recognizes no property lines, so that the carelessness of a single individual may endanger an entire community. Forest fires frequently require the rapid mobilization of large numbers of fire fighters, with the necessary supplies and equipment, and their control by some one in authority. Furthermore, "everybody loses when timber burns." These facts all emphasize the need of an organization which will be state-wide in scope and under public control.

There is some question as to whether such an organization should include scattered areas of wooded land in the more thickly settled districts. Such areas, as a rule, may be more properly classed as suburban property awaiting development than as true forest land, and their protection can well be left to the regular town or city fire department. With this possible exception, experience shows conclusively that the State department of forestry should be made responsible for the prevention and suppression of all forest fires. This is now in effect throughout the Northeast, where the chief need of these departments is for ample authority and appropriations to discharge their responsibility effectively.

The usual and desirable practice of the State foresters is to place one man in complete charge of all fire-control activities, with such technical and clerical assistance as the size and importance of the job warrant. Under this man should be a permanent field force of district fire chiefs, each in charge of an administrative unit, or fire district. The boundaries of these districts may be determined by county, watershed, or other tactical lines, and will vary in size according to accessibility and degree of fire danger.

Each fire district should, in turn, be divided and subdivided into as many units as are necessary for good administration. In one State, for example, there are now four fire districts, in which the township is the next smaller division. For each township there is a town fire warden who reports directly to the district fire chief and who is assisted by one or more deputies. In another State there are three main divisions, each of which is divided by tactical lines such as roads, railroads, and streams into a number of "sections" in charge of section fire wardens. In each section are a number of town wardens, under whom, in turn, come "district" wardens. Political boundaries, however, are used for fiscal purposes only, and the fire-suppression units are organized without reference to town or county lines. In most States local arrangements are made so that temporary laborers, or "listed helpers," may be employed for fire fighting on short notice.

However the details of organization may vary in different States, it is essential that ultimate responsibility for the entire system rest with the State forester. He should have complete authority to appoint, control, and remove every member of the force from the district fire chiefs to the most subordinate local wardens. Lack of such authority is now one of the weakest points in the fire-control system in some parts of the Northeast.

The State organization should also be supplemented by the activities of private owners. Associations of timberland owners formed to provide more effective protection for the holdings of their members have been in existence in several States for years, and might well be more numerous. Educational measures and the maintenance of patrols and lookout towers, either alone or in cooperation with the State forester, usually constitute their chief activities. Additional patrols are often employed by individual owners for their own lands when the protection that the State can give is not regarded as adequate. All such efforts should, of course, be closely coordinated with those of the State forestry department, and it is essential that the district fire chiefs or other appropriate State officials have auhority to exercise complete control over all fire-fighting operations.

FIRE PREVENTION

Complete prevention of all forest fires is obviously the most effective form of fire control. The fire that never starts does no harm. Attainment of this goal is a long way in the future, but more rapid progress toward it than is now being made should be possible. The nub of the problem lies in the reduction of carelessness, which is the cause of at least 95 per cent of the fires in the Northeast.

Carelessness can be overcome most effectively by education and legislation. Many people do not realize what constitutes carelessness with fire in the woods or how disastrous the results of carelessness may be. (Pl. 3, A.) Measures to inform them are already an important part of the activities of most of the State forestry departments and timberland owners' associations. More might well be done in this direction, however, and in addition educational activities might well be made an integral part of the programs of such civic organizations as chambers of commerce, rotary clubs, and farm bureaus. Newspaper and magazine articles, talks, posters, stickers, and moving pictures are all useful forms of publicity.

Patrolmen perform a useful function in both fire prevention and fire detection. For both purposes they can be used to best advantage where most people are to be found in the woods, as along roads, trails, and fishing streams, and at camping places; and also in localities of unusual hazard, such as recently cut-over areas. By warning tourists and other travelers of the fire danger, by instructing them as to the safe use of fire, and by keeping track of their movements, patrolmen can be of great value in reducing the fire danger. In addition, they will often be able to extinguish, while small, any fires set by campers, smokers, and others. In general, the value of a patrolman is to be measured rather by the number of fires he prevents than by the number he extinguishes.

Educational measures should be supplemented by legislation providing penalties for carelessness with fire in any form and declaring anyone guilty of starting a forest fire, whether intentionally or not, responsible for civil damages caused thereby. In addition, the person causing a fire should bear the entire cost of its extinction. There should be a heavy criminal penalty for starting a forest fire maliciously.

The burning of brush or other material on or near forest land is responsible for 10 per cent of the total number of fires. The danger from this source can be lessened either by prohibiting brush burning entirely during a specified fire season or by requiring a permit for burning during the season. If permits are used, they should be procurable through local officials but should be subject to suspension or revocation at any time by the State forester, who should also have authority to stop the issuing of all permits during periods of unusual hazard. Permits should ordinarily be issued for a single day only. They may also well contain restrictions as to the conditions under which the burning may be done; such for example as allowing burning only after 4 p. m., when decreasing temperature and increasing humidity usually lessen the danger of spread; or only if sufficient assistance is at hand to keep the fire under control. The system of requiring brush-burning permits is now generally in effect throughout the Northeast, but its effectiveness could be considerably increased through greater care in the issuing of permits by local officials and through closer supervision of this function by the district fire chief.

Camp fires and smoking are together responsible for nearly 20 per cent of the total number of fires. Camp-fire permits have proved effective in decreasing fire danger and should be generally required in the wild-land sections of the State. Provision should be made so that travelers can obtain permits with as little difficulty as hunting and fishing licenses, and the permits should be subject to suspension or revocation by the State forester at any time. In most of the Northeastern States the governor already has authority to suspend the hunting or fishing season, and in a few to close the woods completely to such classes of persons and for such periods as he may designate. The good results obtained from such suspensions during the last few years have shown the desirability of making the practice general.

Railroads not burning oil are now almost universally required to use adequate spark arresters and to keep their rights of way clear of inflammable débris. In several States the railroads are permitted, subject to the approval of the State forester or the public utilities commission, to establish fire lines immediately adjacent to their rights of way; and in a few States the State forester has authority, during dry periods and in dangerous localities, to require that gasoline speeders patrol the tracks following each train. These latter provisions are desirable and might advantageously be adopted by those States where they do not now exist. The fact that 32 per cent of the forest fires in the Northeast during the 10 years from 1916 to 1925 were due to railroads indicates the importance of taking every precaution to reduce the loss from this source.

Both portable and permanent sawmills operating in the vicinity of forest land should be required, as is now generally the case, to use adequate spark arresters and to clear up all inflammable débris within a radius of 150 feet of the mill. Mill operators and loggers can do much to prevent fires by stopping all smoking by their employees at the mill or in woods during periods of exceptional danger.

Stricter enforcement of the forest-fire laws would help greatly in reducing the number of fires. This requires not only readiness on the part of the fire wardens to bring charges in all cases where there is sufficient evidence, but also, on the part of local prosecuting officials, greater cooperation in obtaining convictions than has sometimes been accorded. A person or corporation actually convicted of breaking the law is far less likely than before to repeat the offense, and serves as a healthy warning to others. In general it is true that from the standpoint of fire prevention there is less need for the enactment of new legislation than for the strict enforcement of that already on the statute books. Much progress has recently been made in this direction, but for the Northeast as a whole both education and law enforcement deserve much more attention than they have so far received.

DETECTION AND SUPPRESSION OF FIRES

Promptness in detecting and suppressing forest fires is next in importance to prevention. A few minutes difference in the time of getting to a fire may make all the difference between a harmless smudge and a disastrous conflagration.

Fire lookout towers equipped with map, field glasses, alidade, and reliable telephone connections are an essential part of the detection system. They were first tried out in Maine as far back as 1908 and are now in general use throughout the Northeast. They are particularly valuable in the more remote, less settled districts where discovery by other means is unlikely. Wherever feasible, they should be so located that every fire can be picked up by at least two towers. This will make it possible to determine much more accurately the exact location of the fire and will considerably increase the chances of prompt detection during hazy weather when the lookout's range of vision is greatly decreased.

All lookout towers, including those maintained in whole or in part by private owners, should be under the supervision of the district fire chiefs, to whom the watchmen should report by telephone at least once and preferably twice a day, in addition to reporting all fires as soon as they are discovered. These watchmen should be on duty at the towers throughout the day during the entire fire season and should, if possible, be men who are personally familiar with the region covered. The system has been well developed throughout the Northeast, where the main needs are now the filling in of occasional gaps and the perfecting of details of operation.

Patrolmen, as has already been indicated, often constitute an important means of fire detection. They should be used freely for this purpose in areas which are much frequented by travelers, which are not visible from a lookout tower, or where efficient telephone communication is not practicable. In many localities it is a great advantage to have patrolmen equipped with a portable telephone set so that they can report promptly any fire too large to handle alone. It is also desirable to encourage local residents and transients to act as a sort of volunteer patrol force by keeping a sharp watch for fires and reporting them at once to the proper official. In the more thickly settled districts where such cooperation has been well developed, reports of fires are received about as frequently from these sources as from lookout towers.

When a fire has been reported, the essence of efficient suppression lies in reaching it at the earliest possible moment with sufficient men adequately supplied with fire-fighting equipment. Except when caught in their earliest stages fires must ordinarily be fought by organized crews varying in size from a few men to several hundred. The local warden and the district chief must, therefore, be ready to mobilize at least a small crew at a moment's notice, and to supplement this initial force as rapidly as circumstances may demand. Promptness in responding to a call and in getting to the fire is the criterion of effective organization. Where settlement is sparse, this involves the construction and maintenance of sufficient roads and trails to make all parts of the forest reasonably accessible.

No arbitrary limit can be set as to the time within which all fires must be reached to prevent their getting beyond control. This varies greatly with the kind of forest and with the prevailing weather conditions. A lightning fire in a northern hardwoods forest during a moist spell may smoulder for hours before becoming dangerous. On the other hand, an escaped camp fire in the pine woods of southern New Jersey during a dry, windy spell may be completely out of control within five minutes. In general, it is important to reach every fire at the earliest possible moment, and as the hazard increases this becomes more and more essential.

It would be out of place in this bulletin to discuss in detail fire-fighting methods. Emphasis can, however, properly be laid on a

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FOREST FIRE IN THE WHITE MOUNTAINS

A, The forest fire spreading uphill not only kills the timber but destroys organic matter in the soil; B, fire following logging has set back forest regrowth indefinitely and exposed the area to the evils of erosion.

F-17526 F-58911

THE PENALTY OF LACK OF ADEQUATE FIRE CONTROL

A, A double burn turns forest land to rocky waste; B, repeated fires have changed once thrifty forest into "barrens."

few facts of outstanding importance. First of all, it is poor policy to attempt to economize on men or materials. In the long run, it will prove cheaper to have too many rather than too few men, and to supply them with ample shovels, rakes, mattocks, axes, pumps, chemical extinguishers, and other equipment. As studies of the relation between weather conditions and fire hazard progress, it will become possible to gauge more accurately the danger under any given set of conditions, and hence the number of men really needed. In the second place, one man should be in complete charge of the entire force. Divided responsibility is as fatal in fire fighting as in military operations. Moreover, the man in charge can handle the situation best, particularly in large fires, by devoting his attention almost wholly to supervision rather than to actual fire fighting. Finally, a fire apparently under control should never be left without an adequate patrol until there is no question as to its being completely out. The establishment of effective fire lines, and the "mopping up" of places inside of these lines where the fire is still burning, are just as important as stopping the spread of the fire. Too many fires have come to life and caused serious damage after having been abandoned as no longer dangerous.

SAFETY IN SLASH DISPOSAL

Slash, or the tree tops and branches resulting from logging operations, increases the fire danger and makes fire fighting more difficult. This condition persists for about 12 to 15 years in spruce and pine stands, and for 3 to 5 years where hardwoods have been cut. It takes about this length of time for decay to progress to the point where hazard from slash is practically eliminated. The most acute danger is in the early years—for softwoods, perhaps the first five; for hardwoods, perhaps the first two.

The increased danger also varies greatly with the amount of slash left. Because of the close utilization now common in the Northeast, the danger is much less there than in many other regions. Fuel wood, pulpwood, and acid wood are usually cut to top diameters of 2 to 4 inches, and even saw logs may be cut from trees of some species, such as northern white pine, to a top diameter of 5 or 6 inches. Even under the most favorable conditions, however, the smaller branches and twigs are never wholly utilized, so that logging operations always result in some slash and consequent increase in the fire danger.

Complete disposal of slash by piling and burning would be ideal from the standpoint of fire control. This method is already in use on softwood cuttings in the White Mountain National Forest and by a few private owners, and should be more generally adopted where the slash is heavy or the fire risk high.

The next most desirable method of slash disposal is lopping and scattering the branches of softwoods so as to bring them into contact with the ground and thus hasten decay. This is accomplished almost automatically with close utilization, so that in pulpwood operations, at least, the New York law requiring the lopping of softwood slash to a 3-inch diameter limit necessitates virtually no change in present practice. As for hardwood slash, decay is apparently no

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more rapid with lopped than with unlopped material, except for a few species such as oak and chestnut (*44*).

The cost of either piling and burning or of lopping and scattering varies widely with the character and quantity of the slash and with the skill of the operator. In Massachusetts and New Hampshire the cost of piling and burning white pine slash has ranged from 50 cents to $1.50 for every thousand board feet of timber cut. On the White Mountain National Forest $1.50 a thousand is allowed for burning softwood slash as the logging progresses and $1 for lopping hardwood slash, or an average of about $1.25 a thousand in mixed stands. Experiments on a pulpwood operation in northern New Hampshire indicate a cost of about $1 a cord for piling and burning (*4*). On the Susquehannock State Forest in Pennsylvania, lopping and scattering the brush in an overmature stand of beech, birch, and maple cost from 50 to 70 cents a thousand.

High costs have usually been due to the fact that slash disposal was carried on as a separate operation from logging, or to the fact that the men handling it were not experienced or interested in the work. It has been the general experience in the national forests of the West, where brush disposal is almost universally required, that costs drop steadily as the men become more familiar with the work and as their interest and belief in it increase. Some operators state that the cost of brush burning is partially or wholly offset by the decreased cost of logging resulting from clearing up the area.

In the Northeast, where slash disposal has not been generally practiced, the average net cost by either burning or lopping could hardly be reduced in the near future to less than 75 cents a thousand and might easily run as high as $1 a thousand. This would mean an annual expenditure of $1,600,000 to $2,000,000 to handle the slash resulting from the present cut of lumber and pulpwood. The larger amount is nearly equal to the combined present fire damage and cost of fire control. Moreover, universal slash disposal would not permit any material reduction in the $1,000,000 now spent for control activities, nor would it eliminate all fire damage.

Considering the present close utilization of timber and the steadily increasing efficiency of State fire-control organizations, it is doubtful whether universal slash disposal, with its high cost, can be regarded as an essential feature of adequate fire control. Nearly all of the Northeastern States do, however, require the disposal of slash along public roads, and this requirement might well be extended to other especially dangerous places. Thus, all slash resulting from the building of public or private roads or from the construction of railroads should be piled and burned as the construction proceeds. In addition, strips on each side of regularly traveled roads or trails should be left uncut, or the slash resulting from cutting should be disposed of by piling and burning. Safe widths for such strips are 75 feet on main highways, 50 feet on secondary highways and logging roads, and 25 feet on trails.

The State forester should also be given authority to declare any unusually dangerous slash-covered areas a public nuisance, and to require the disposal of slash thereon. This would make possible the more adequate protection of small woods settlements and individual homes and of particularly exposed stands of valuable timber menaced by adjacent slash. In lieu of slash disposal, he should also have authority to require adequate patrol of recently cut-over areas by their owners during periods of acute danger. Such patrol constitutes an effective means of protection during the particularly dangerous years immediately following cutting, and might well be much more generally provided by owners of their own volition than is now the case.

STANDARDS AND COST OF FIRE CONTROL

Estimates by State foresters as to the sums needed for protecting State (including county and town) and private forest lands from fire are compared in Table 3 with the amounts actually budgeted for protection purposes for the fiscal year 1926–27.

TABLE 3.—*Amounts budgeted for fire protection in the Northeast, 1926–27, and estimated cost of protection needed*

State	Amounts budgeted for protection				Estimated cost of protection	
	State and private	Federal	State, private, and Federal			
			Total	Per acre	Total	Per acre [1]
Maine	$205, 760	$33, 300	$239, 060	$0. 016	$450, 000	$0. 030
New Hampshire	62, 000	9, 940	71, 940	. 017	134, 300	. 031
Vermont	13, 140	5, 830	18, 970	. 005	78, 800	. 021
Massachusetts	63, 000	12, 630	75, 630	. 023	170, 700	. 052
Rhode Island	8, 310	1, 070	9, 380	. 034	14, 400	. 051
Connecticut	23, 560	4, 440	28, 000	. 019	60, 000	. 040
New York	213, 745	28, 750	242, 495	. 026	388, 500	. 041
New Jersey	75, 620	6, 100	81, 720	. 043	82, 400	. 043
Pennsylvania	172, 605	29, 120	201, 725	. 016	393, 500	. 030
Total	837, 740	131, 180	968, 920	. 018	1, 772, 600	. 034

[1] Based on the area regarded as in need of organized protection, which does not always equal the total forest area of the State.

These figures do not include expenditures by private owners which are not made under the direct supervision of the State forester. The exact amount of such expenditures is not known, but would undoubtedly add considerably to the totals given. The estimates represent what in the best judgment of the State foresters is needed to provide a reasonable degree of protection at a reasonable cost and do not contemplate the elimination of all fires. In fact, the number of fires, although important, is of less significance than the area burned, which is generally regarded as a fair measure of the effectiveness of the protection organization.

Table 2 shows that the ratio of area burned to total forest area during the 10 years from 1916 to 1925 ranged from 0.03 per cent in Vermont to 3.04 per cent in New Jersey, with an average of 0.56 per cent for the entire Northeast. The maximum was perhaps reached in the anthracite section of Pennsylvania during the spring of 1923, when 734 fires burned more than 13 per cent of the total forest area in the section.

The difficulty of fire control varies so greatly with the character and accessibility of the forest, the extent to which and the way in which it is cut, the number of persons visiting it, the climate, and other factors, that it is impossible to set any arbitrary relation between area burned and total forest area as representing a fair standard of efficiency under all conditions. The ratio of 0.1 per cent, which has been more or less discussed as such a standard, may be too high for the four northern States and too low for the five southern States. In Vermont, for example, the area burned is now kept down to 0.03 per cent of the total forest area at an annual cost of 0.5 cent an acre, while in the pine region of southern New Jersey it is estimated that an organization capable of reducing the burned area to 0.1 per cent would cost 40 cents an acre.

The estimated costs of protection represent the best judgment of their authors as to what is needed to attain a reasonable standard of efficiency, which is not necessarily the same under the widely varying conditions in the different States. In most States they would necessitate an aproximate doubling of the present budget. By the time this has been done, it is not unlikely that further increases will be regarded as desirable. As forest lands become more valuable and the importance of their protection more generally appreciated, there is little doubt that higher standards will be set and larger sums made available for their attainment.

PLANTING

WHERE PLANTING IS NECESSARY

Planting is essential for continued forest production:

On lands which have been so severely burned as to preclude natural reproduction. These probably comprise in the aggregate an area of several million acres and are chiefly lands which have been burned more than once.

On unburned cut-over lands where logging has not been followed by satisfactory natural reproduction. There is a relatively small area of such lands where tree growth is practically lacking, but a very large area where the natural reproduction is not satisfactory.

On abandoned farm lands which are reverting to forest slowly or not at all. These constitute a large area and offer one of the best opportunities for restoring once forested land to productivity.

PLANTING STOCK

Conifers are much more widely used for planting than hardwoods. This is largely because they thrive better under the adverse conditions which usually prevail on areas where planting is most necessary. As a result of repeated burning, cutting, cultivating, or pasturing such areas are apt to be characterized by worn-out, shallow, or infertile soils and by a growth of grasses, weeds, and shrubs which offer severe competition to the small trees. Under these conditions even conifers may grow slowly at first, but their survival is usually greater and their yield of usable material higher in the same period than is true of hardwoods. Hardwoods, if planted at all, should be confined to the more moist and fertile sites.

Northern white pine [4] has been more generally planted than any other tree and is well adapted to a wide variety of sites. When

[4] For the botanical names of tree and shrub species mentioned in this bulletin, see p. 109.

used, however, it must be protected against the blister rust, a serious disease now prevalent throughout the Northeast, by the methods described later in the discussion of the white pine types. It is also subject, particularly in pure stands, to damage by the white pine weevil. Norway pine is another vigorous and valuable tree which deserves to be more widely used than at present, since it thrives even better under adverse conditions than the white pine and is less subject to attack by insects and disease. Scotch pine, a native of Europe, usually starts well on poor soils, but can not be highly recommended for general use because of its tendency to be of poor form and to suffer from snowbreak. Norway spruce (another European tree) and white spruce require somewhat better sites, but are nevertheless hardy and desirable trees, suitable for rather general use, particularly in the northern part of the region. Mixed plantations, as of white and Norway pine, or of pine and spruce, although not so far widely used, have the advantage of being less liable to complete destruction in case of attack by insects or disease.

In general, it is a safe rule to choose those species which occur naturally or which have been planted successfully on sites similar to those to be planted. Exotic species are of doubtful value, except on sites where their success has been demonstrated by actual plantations. It is also safe for those without previous experience in planting to seek advice from their State forester as to the best species or combinations of species to select out of the very wide variety that might be used.

Experience has shown that in the long run thrifty nursery stock is cheaper and gives better results than wild stock or the direct sowing of seed on the land to be reforested. The best age and size of stock to use depend on the species and on the character of the area to be planted. Two-year-old seedlings of pine may be satisfactory where there is little competition from grass, weeds, and brush, whereas 3 or even 4 year old transplants may be needed where such competition is likely to be severe. For spruce, 3 or 4 year old transplants are usually desirable. Conifer seedlings or transplants for field planting may well range from 4 to 6 inches in height and should preferably have vigorous bushy tops and a good bunch of fine roots. These can be handled more easily and cheaply than can larger plants. Hardwoods develop much more rapidly in the nursery and can best be planted as 1 or 2 year old seedlings.

Young trees for planting can be grown by the timberland owner in his own nursery or purchased from a State or commercial nursery. (Pl. 5, A.) State nurseries from which stock can be obtained for plainting within the State are maintained by the forestry departments of Maine, New Hampshire, Vermont, Massachusetts, New York, New Jersey, and Pennsylvania, and by the Connecticut Agricultural Experiment Station. Names of reliable dealers can also be had from these sources.

ESTABLISHING THE PLANTATION

In the spring, as soon as possible after the frost is out of the ground, is generally considered the best season for field planting (*48*). Considerable success has, however, attended planting in the fall after growth has ceased but before the ground freezes. In either event, moist soil at the time of planting is essential. Planting should also preferably be done on cool, foggy, or drizzly days, and the roots of the young trees, particularly of conifers, should not be allowed to dry out.

The trees are usually planted in rows with a spacing of 8 by 8 to 6 by 6 feet. This requires 680 to 1,200 trees to the acre. The wider spacing is used when it is desired to cover a considerable area at low cost, or when rapid growth is desired at the expense of quality. For most purposes a spacing of 6 by 6 feet, or a little more, will prove satisfactory. Spacings as close as 4 by 4 feet, or even 3 by 3 feet, may sometimes be desirable for special purposes, such as the growing of bean poles or Christmas trees or minimizing the damage by the white pine weevil, but they should not be used when the production of lumber is intended, unless subsequent thinning to prevent overcrowding is practicable.

Careful setting of the young trees to give them a good start is important. (Pl. 5, B.) Any heavy growth of sod or weeds should first be cleared off for a space of at least a foot square. A hole should then be dug deep enough and wide enough to accommodate the roots, and the better top soil should be kept separate from the poorer soil. The roots of the tree to be planted should be well spread out in the hole and the topsoil pulled in over them and packed down with the closed fist. Loose trash, grass, weeds, and moss should not be used, since they can not be packed tightly and are likely to result in the drying out of the roots and the consequent death of the plant. Enough additional soil should then be pulled in so that when it is well firmed it will fill the hole to the ground level. The tree itself should be set at about the same depth in the soil as it stood in the nursery. Finally, it should be surrounded by a shallow layer of loose soil to act as a mulch.

Where the soil is light and free from rocks, planting can often be done successfully by setting the trees in slits made with a spade, mattock, or grub hoe. The slits are made by driving the tool into the soil to the full depth of the blade and working the handle back and forth. The roots are then inserted in this V-shaped opening, and the soil is pressed around them with the foot or by again driving the spade into the soil about 4 inches away and forcing the soil over against them. The chief objection to this method is that the roots can not be so well spread out or the soil packed so firmly around them. It is therefore not so sure as planting in holes, but can be carried on about twice as rapidly.

Where cultivation is possible, the plants can advantageously be set out in plowed furrows. On such sites subsequent cultivation is also beneficial in reducing the competition of other vegetation.

COSTS AND YIELDS

The cost of planting stock varies widely. In Maine, New Hampshire, Vermont, Massachusetts, New York, New Jersey, and Pennsylvania stock is distributed to residents of the State at approximately the cost of production plus shipping charges. Prices run from a minimum of $2 a thousand for 2-year-old seedlings to $10 a thousand for 3-year transplants. The cost from commercial nurseries is usually somewhat higher.

On average sites one man can plant at least 500 trees in an 8-hour day. With labor at $4 per day, and with 1,000 trees to the acre, this would mean a cost of $8 per acre for the actual planting. Where planting is unusually difficult, or where closer spacing is used, the cost would naturally run somewhat higher, and somewhat less where planting is easier or spacing wider. Under ordinary conditions the total cost of stock and planting will vary from about $10 to $20 per acre, with an average of perhaps $15 per acre.

The yield will vary chiefly with the quality of the site, the species and spacing used, and the subsequent treatment given the plantation. Cultivation of the soil during the early years will increase growth, but on most of the areas where planting will be done cultivation is so difficult and expensive that the results will hardly justify the cost. Cutting back the brush is often profitable, where much is present and it threatens to choke out the planted trees. As the stands become older, cutting out the poorer trees will help the growth of the better and will often be immediately profitable where the material removed can be marketed. These operations will be discussed in more detail later in connection with specific forest types.

Comparatively few plantations in the region are yet old enough to indicate conclusively what yields can be expected when they reach merchantable size. In general, the yields should be at least as large as those from well-stocked natural stands on similar sites, for which the available figures are given later.

A study in 1921 (*15*) of 16 northern white pine plantations in Rhode Island, Massachusetts, and New Hampshire, comprising the bulk of all pine plantations in New England over 25 years old, showed yields ranging from 11,160 board feet per acre at 27 years of age to 44,440 board feet per acre at 63 years of age. These were all on abandoned farm lands, which were doubtless characteristic of such lands in need of reforestation. The spacing varied from 4 by 4 feet to 22 by 25 feet, but in 12 of the plantations spacings of 6 by 8, 8 by 8, 8 by 10, or 10 by 10 feet were used. The average spacing was therefore somewhat wider than is now common. Beyond the removal of dead and badly suppressed trees, only one of the plantations had been thinned. This thinning, in 1908, yielded 14,000 board feet of box boards and 40 cords of wood, with a net profit of $20 per acre.

Plotting the figures for these 16 plantations on cross-section paper and drawing a smooth curve through the points thus obtained gave the average yields indicated in Table 4. These yields are slightly lower from 40 years on than those of well-stocked natural stands on sites of average quality. They probably indicate the minimum that can reasonably be expected from successful plantations of white pine on abandoned farm lands, and somewhat more than can be expected on soils of poorer quality.

TABLE 4.—*Yields of northern white pine on 16 plantations in New England, 1921*

Age (years)	Yield	Average annual growth	Age (years)	Yield	Average annual growth	Age (years)	Yield	Average annual growth
	Board feet	*Board feet*		*Board feet*	*Board feet*		*Board feet*	*Board feet*
25	6, 200	250	40	21, 500	540	55	34, 000	620
30	11, 500	380	45	26, 000	580	60	37, 400	620
35	16, 600	470	50	30, 100	600	65	40, 400	620

Yields from Norway pine plantations should run at least as high as for white pine (*36*). Scotch pine grows more rapidly at first but does not hold out so well. Both European larch and Japanese larch make extremely rapid growth in height in their early years, but natural thinning soon results in stands so open as to make it doubtful that these species can equal the pines in volume production.

Norway spruce and white spruce grow slowly at first, but more rapidly later, and maintain fairly dense stands. An exceptionally fine 44-year-old plantation of Norway spruce in Vermont in 1924 yielded 49.2 cords, or about 25,000 board feet, per acre. In northwestern Pennsylvania, a 42-year-old plantation of Norway spruce, with some Scotch pine and hardwoods, had in 1925 a total yield of 47.4 cords per acre. In general, spruce can be expected to yield somewhat less than pine in the same period in total cubic feet, or cords, and considerably less in board feet.

Average figures of the financial returns from plantations are difficult to give because of the many items which must be considered, such as the cost of planting, administration, protection, and taxes, in relation to the probable amount of material to be produced and its stumpage value. Specific cases indicate that northern white pine on soil of medium quality will usually return from 4 to 6 per cent compound interest on the total investment. Planting is therefore not only necessary to restore many areas to productivity, but except on very poor sites or in remote localities where stumpage values are apt to continue low, is likely to prove a profitable operation. In estimating returns, consideration should be given to the fact that many of the Northeastern States provide preferential taxation for plantations.

That the prospects of reasonable profit are sufficiently good is attested to by the fact that forest planting is markedly on the increase. Planting affords the only means of restoring many idle areas to productivity in a reasonable time, and can often be used to advantage to increase the productivity of existing stands, as will be indicated later.

SUMMARY OF MEASURES NECESSARY TO KEEP FOREST LAND PRODUCTIVE

FIRE CONTROL

Although large areas in the Northeast have been laid waste by fire and reduced in productivity by injudicious cutting, natural conditions are so favorable for tree growth that some kind of forest is reasonably sure to follow cutting if fires are kept out. The new

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PLANTING OPERATIONS ON THE EWING STATE FOREST IN MASSACHUSETTS

A, Nursery where forest trees are raised for planting on State lands and for distribution to private timberland owners; B, a crew setting out white pine transplants on a cut-over area in need of reforestation.

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ABANDONED PASTURES ARE HIGH-GRADE FOREST LAND

The Norway pine plantation shown in B is on light sandy soil and outcropping rock similar to the old field in A.

forest will often not be satisfactory from the standpoint of stocking or species represented, but will be sufficient to prevent denudation. Fire control is therefore nearly the only requirement that is absolutely necessary to keep most land already forested at least partially productive. Full production is quite a different matter, requiring adequate protection against animals, insects, and diseases, together with the proper silvicultural treatment of the forest.

The most essential features of adequate fire control are:

Centralization of control activities in an organization which is statewide in scope and under public control (preferably the State forestry department).

Division of the State into fire districts and subdistricts, with competent officials in charge of each.

Maintenance of lookout towers for the prompt detection of fires.

A suppression organization that can get a properly equipped crew of sufficient size to every fire at the earliest possible moment.

Fire crews instructed to keep close watch of every fire, even after it is under control, until it is completely out.

Penalties for carelessness with fire in any form.

Authority to put a stop to hunting or fishing, or to close the woods completely, during periods of exceptional danger.

Permits for burning brush or lighting camp fires during the fire season.

Use of spark arresters by railroad engines not burning oil, and by sawmills operating in the vicinity of forest land.

Disposal of slash along highways and main logging roads and in other unusually dangerous places.

Elimination of inflammable débris on railroad rights of way.

Patrol of railroad tracks during dry periods and in dangerous localities.

Reduction of carelessness by educational measures and strict enforcement of the law.

Cooperation of timberland owners, either individually or through associations, with the State organization, and such additional precautions on their part as may be necessary to safeguard their own lands.

The cost of these measures will probably vary from 2 to 10 cents per acre of forest land, depending on local conditions. Practically all of them are in effect in one or more of the Northeastern States, and many of them in all.

PLANTING

Planting is necessary to restore forest productivity on lands which have been so severely burned as to prevent natural reproduction, on occasional unburned cut-over areas which have not reproduced naturally, and on abandoned farm lands which are not reverting to forest (Pl. 6). Thrifty nursery stock of species adapted to the site and large enough to compete successfully with any other vegetation on the ground should be used. Protection against fire and pests should be assured before and after the plantation is established. Yields at least equal to those of well-stocked natural stands on similar sites may be expected from such plantations.

PRODUCING FULL TIMBER CROPS

THE REAL FOREST PROBLEM

Merely keeping some kind of tree growth on forest lands is a step in the right direction, but only a step. The real forest problem in the Northeast is how to produce full timber crops on lands now partially idle. More specifically, it is one of building up large areas of run-down, often badly run-down forests. Even where fire has been kept out, cutting and subsequent neglect have rather generally resulted in a progressive deterioration which is evidenced by poorly stocked stands and increased representation of the less desirable species. To-day comparatively little forest land in the region is producing the yield of which it is capable.

This is a situation which can hardly be viewed with complacency by either the public or the individual timberland owner, particularly in view of the fact that conditions are so favorable to the practice of forestry. Stumpage values are high, ample markets are close at hand, and the more valuable trees respond readily to treatment. The estimates by the Forest Service given in Table 5 bring out clearly the differences in rate of growth which may be expected (1) under present conditions: (2) under "crude forestry," by which is meant fire control and, in some regions, such simple silvicultural measures as the leaving of seed trees when the timber is logged; and (3) under "intensive forestry," by which is meant the intensive management of forests as crops.

TABLE 5.—*Estimated annual rate of growth per acre in different northeastern forests under different degrees of management*

Character of forest	Under present conditions	Under crude forestry	Under intensive forestry	
			Average	Maximum
	Cubic feet	*Cubic feet*	*Cubic feet*	*Cubic feet*
Spruce and fir	20	25	45	80
Birch, beech, and maple	25	30	60	120
White pine	40	45	100	170
Oak and mixed hardwoods	25	30	60	120
Oak and pine	22	27	65	105

Since comprehensive data are not available regarding present and probable future growth under the wide variety of forest conditions in the Northeast, these estimates are at best approximations. They are believed, however, to be conservative with respect to the increased growth possible under intensive forestry. If so, it is evident that efficient management will pay as well in timber growing as in agriculture, manufacturing, or any other enterprise. In fact, intensive forestry may be the only means of converting a run-down, neglected forest into a profitable investment. European experience has proved that within reasonable limits increased expenditures for forest management mean increased net returns, and there is no reason why this should not be equally true in the United States.

With more than 90 per cent of the forest land in the Northeast in private ownership, increased production must result chiefly from the efforts of individual timberland owners. Unlike fire control, which must be handled by a single organization that is state-wide in scope and authority, intensive forestry on areas under different ownership does not lend itself so readily to centralization.

This does not mean that public participation in timber growing should be limited to fire control. The interest of the entire community in the proper use of forest land and the production of adequate timber supplies is sufficient to justify State activity in such other directions as the distribution of planting stock, the conduct of research, and the dissemination of information as to the best methods of forest protection, production, and utilization, the acquisition and management of State forests, and the placing of forest taxation on an equitable basis. Legislation aimed at maintaining forest production through a certain degree of State control over private cuttings may even be desirable.

It is hardly conceivable, however, that these measures, all of which are now in force in one part or another of the Northeast, would by themselves result in maximum production. Short of actually taking over the management of all forest lands, the State can go only so far in the way of help or coercion. Beyond that point the production of full timber crops is in the hands of the individual owner.

WHAT INTENSIVE FORESTRY INVOLVES

Adequate fire control along the lines discussed is obviously the first essential for intensive forest management. It is worse than useless to spend time and money in building up a forest which is likely to be burned over at any time. The owner who is really interested in getting the most out of his land will, therefore, supplement State activities by taking such additional precautions as are necessary to safeguard the forest property effectively from fire. These may include more complete disposal of slash than the law requires, special patrol, maintenance of an adequate supply of fire-fighting equipment, and the liberal use of fire-warning signs and posters.

Next in importance to fire control comes protection from other destructive agencies, such as insects and diseases, and then silviculture, or the art of producing and tending the forest itself. While insects and diseases seldom cause devastation comparable to that resulting from fire, they may, if uncontrolled, virtually prevent the growing of certain trees. This is true, for example, of the chestnut blight and the white pine blister rust. Moreover, they are responsible for a steady drain on the forest which, with the system of fire control now in effect, probably results in a larger total loss than that due to fire.

Silviculture includes methods of establishing the forest and of caring for it so as to obtain the maximum yield of desirable species. It goes hand in hand with protection from insects and diseases, of which it is often the most effective means. Detailed suggestions for the treatment of different forest types will be given later.

The next step beyond keeping the land productive through protective and silvicultural measures is to plan cutting operations so as to obtain a regular income. Since the forest is a crop which requires many years to reach maturity, this necessitates (1) maintaining a constant growing stock, or forest capital, and (2) limiting the amount of timber cut during any given year or period of years to approximately the amount grown, or the income produced by this capital, during that period. When more than this amount is cut, the difference represents the extent to which the forest capital, and consequently its income-producing power, have been depleted.

The principle involved can best be illustrated by a hypothetical example. Imagine a 2,000-acre tract of white pine which is growing at the average annual rate of 750 board feet per acre, with a yield of 37,500 board feet in 50 years. Imagine further that this tract is divided into 50 units of 40 acres each, with stands ranging regularly in age from 1 to 50 years. Each unit will then contain 1,500,000 board feet when it is 50 years of age. This amount can, therefore, be removed year after year indefinitely, provided cutting on each unit is followed by satisfactory reproduction, since in 50 years the original stand will have been replaced by a new one of equal volume. In this example the growing stock, or capital, is 37,500,000 board feet and the annual growth, or income, 1,500,000 board feet.

Such ideal conditions are, of course, never found in nature. On any area of considerable size, sites vary in quality; stands are irregular in age, composition, and rate of growth; and fire, insects, diseases, wind, drought, and other factors upset the best-laid plans. Nevertheless, it is possible to determine the growing capacity of even the most irregular forest much more accurately than is now customary, and to regulate its utilization accordingly (*9*). The methods by which this is done can not be considered in this bulletin, but attention is called to the importance of sustained yield in placing the management of a forest property on a thoroughly businesslike and effective basis.

The outstanding advantage of maintaining an ample growing stock is that it permits a regular income. The most common objection to forestry is that taxes, protection, and other costs must be carried over many years as compound interest before the forest can be harvested and a return realized. This is true only when forestry starts with bare land or young stands. Compound interest holds no terrors for the owner where property consists partly of merchantable timber and partly of young growth, and who handles it so as to maintain a balance between growth and cut. Current expenditures can then be met from current receipts as in any other business; and compound interest can be as completely forgotten by the timberland owner as it is by the farmer or the merchant.

Finally, intensive forestry requires a definite and clear-cut plan of management. The owner should know where his property lies, of what it consists, how it is to be protected, what methods of cutting and subsequent treatments are to be used in different types, how much timber can be cut each year, and where such cutting should be located. For large areas these facts and plans should be recorded in permanent form. They should also be revised and brought up to date from time to time as changing conditions make this necessary. For small areas, such as farm wood lots, a written plan is less necessary; nor is so strict an application of the principle of sustained yield possible. Every owner will, however, find it to his advantage to know his forest thoroughly and to plan on handling it so that it will yield as large and as regular a return as possible.

SPRUCE AND NORTHERN HARDWOODS REGION

The spruce and northern hardwoods region is characterized by an abundance of spruce, balsam fir, sugar maple, yellow birch, paper birch, and beech. Other common species are northern white cedar, tamarack, eastern hemlock, basswood, white ash, red maple, and the aspens. Northern white pine now occurs only scatteringly, although it is largely from this region that the famous white pine masts of colonial days were obtained. The principal forest types are spruce-swamp, spruce-flat, spruce-hardwoods, spruce-slope, old-field spruce, northern hardwoods, and birch-aspen. The northern white cedar type occurs fairly commonly in swamps in many parts of the region, but hardly occupies sufficient total area to require discussion here.

The region occupies all of northern and central Maine, northern New Hampshire and Vermont, and the Adirondack Plateau in New York. It extends south through the Green Mountains to the Berkshires in western Massachusetts, and reappears in the Catskills and in northeastern Pennsylvania. It is confined for the most part to the more remote and less thickly settled sections with poorly developed transportation facilities, as in northwestern Maine, which probably affords as good an example of real wilderness as is to be found anywhere in the country.

SPRUCE TYPES

The five spruce types—spruce-swamp, spruce-flat, spruce-hardwoods, spruce-slope, and old-field spruce—have so much in common that they can best be considered together. They are found only in the spruce and northern hardwoods region, where they furnish the bulk of the pulpwood supply. The spruce-flat, spruce-hardwoods, and spruce-slope types easily stand first in importance both commercially and geographically. The spruce-swamp and old-field spruce types cover relatively small areas, but the old-field spruce is of considerable importance locally because of its accessibility and usually large yields.

The spruce-swamp type occupies low, poorly drained sites with high water table and impervious soil of peaty character. Black spruce is the predominating species. Red spruce, balsam fir, tamarack, and northern white cedar are also common, with a sprinkling of black ash, red maple, and paper birch. Growth is very slow, and the mature trees are of small size.

The spruce-flat type occupies flat sites at low elevations where the drainage is better than in the swamps but poorer than on the slopes. Red spruce and balsam fir are the principal species and often form 90 per cent of the stand. Paper birch is sometimes common, particularly on burned areas, and other hardwoods usually occur scatteringly.

The spruce-hardwoods type occupies the well-drained slopes at medium elevations just above the spruce-flat type. Red spruce is the most abundant single species, with balsam fir frequently a close second. White spruce is common in parts of Maine and New Hampshire, but rare elsewhere. Yellow birch, paper birch, sugar maple, red maple, and beech, in widely varying proportions, often make up 50 per cent of the stand. Eastern hemlock and northern white pine are also common associates. In spite of the great range in composition in different stands, the type is readily recognized by the abundance of spruce in mixture with hardwoods. Except possibly on old fields, spruce makes its most rapid growth and is of the best quality in this type. (Pl. 7.)

The spruce-slope type occupies steep, thin-soiled slopes at the upper elevations. Red spruce predominates, and often forms as much as 90 per cent of the stand. Balsam fir is locally abundant. Paper birch is common, but other hardwoods are scarce. Growth is slower than in the spruce-hardwoods type, but the stand is sometimes heavy. Toward timber line the trees become short bodied, small, and scrubby.

The old-field spruce type occupies land at one time cleared for agriculture, mostly for pasture, and is confined chiefly to northern New England. Pure stands of red spruce are most common. White spruce and balsam fir frequently occur in mixture with it, however, and pure stands of white spruce are not uncommon in Maine and New Hampshire. Other species occur only scatteringly. Soil conditions are usually good, with the frequent result that growth is rapid and yields are heavy.

The original spruce forests, except where they followed fire or windfall, were typically uneven aged. This condition was not radically changed by the early cuttings, which took out only the larger trees down to a breast-high diameter of 12 to 14 inches. Subsequent cuttings, however, have been increasingly heavy, until to-day a virtual clear cutting is the rule in pulpwood operations. As a result, future stands, not only in the old-field type but in other types, are likely to be increasingly even aged.

NATURAL REPRODUCTION [7]

Most of the species in the spruce types are so tolerant of shade that, except in the densest stands, a good "advance growth" of young seedlings and saplings is usually present. These young trees come in gradually, and the most tolerant, such as spruce, balsam fir, and maple, are able to persist for many decades in a suppressed but healthy condition under a fairly heavy overhead cover. Thus, spruce seedlings in a typical spruce-hardwoods stand usually average only about 3 feet in height at 30 years and 4.5 feet at 40 years. They are, however, able to recover readily from suppression, and a prompt and marked increase in growth usually follows the removal of the larger trees.

Studies of reproduction in the spruce-flat, spruce-hardwoods, and spruce-slope types in northern New England and New York show clearly (Table 6) that ample material for the production of well-stocked stands is ordinarily found on areas that have been heavily cut for pulpwood. Most of the spruce and balsam fir were on the ground at the time of the cutting, but many of the hardwoods came in later. The general failure of spruce and balsam fir to reproduce themselves naturally after cutting on areas where they were originally abundant is a striking and important fact.

[7] Most of the material in this section has been taken from a very detailed report by M. Westveld, of the Northeastern Forest Experiment Station, entitled "Reproduction on Pulpwood Lands and Suggestions for Their Management." Grateful acknowledgment is made to Mr. Westveld for permission to use the facts brought out in this manuscript prior to its publication.

TABLE 6.—*Number of trees per acre on cut-over lands in the spruce types in the Northeast*

Type	Spruce and balsam fir	Other species [1]	All trees
Spruce-flat [2]	3,015	1,154	4,169
Spruce-hardwoods [3]	1,689	3,176	4,865
Spruce-slope [4]	6,251	4,949	11,200

[1] Chiefly yellow birch, sugar maple, aspen, striped maple, mountain maple, and pin (fire) cherry.
[2] Data are from 245 plots from 2 to 40 years after cutting.
[3] Data are from 152 plots from 5 to 40 years after cutting.
[4] Data are from 16 plots from 3 to 15 years after cutting.

This failure is probably due in part at least to unfavorable seedbed conditions and to heavy early mortality. In uncut stands the thick layer of partially decomposed litter usually present is sufficiently moist to permit the ready establishment of spruce and balsam fir reproduction. After cutting, however, this litter dries out rapidly, with the result that these species are able to establish themselves only on such mineral soil as has been exposed by logging.

The relative abundance of spruce and balsam fir in comparison with hardwoods and other trees in the original stand and at various intervals after cutting is shown in Figure 5. Trees 1 inch or more in diameter at breast height are included in the original stand, and trees of all sizes in the cut-over stands. In general, the number of spruce and balsam fir present during the first few years after cutting is roughly proportional to their volume in the original stand and decreases steadily as the volume of the hardwoods increases. It is not unusual, however, to find considerable numbers of coniferous seedlings even in stands having a high percentage of hardwoods.

The most striking facts brought out by the comparison in Figure 5 are the ability of spruce and balsam fir to hold their own in the spruce-flat type, where the poorly drained soils are unfavorable to the hardwoods, and the marked encroachment of hardwoods and others in the spruce-hardwoods type and the spruce-slope type. This encroachment is probably permanent in the spruce-hardwoods type. Favorable soil conditions, abundance of seed, ability to come in after cutting, and rapid early growth all tend to give hardwoods the advantage and to enable them to crowd out the spruce and balsam fir. In the spruce-slope type all of the plots measured were on areas which have been cut so recently as to leave the final result uncertain. Conditions there are not so favorable for the hardwoods, however, and the spruce and balsam fir, whose persistence more than compensates for their slow start, will probably regain in time their dominant position.

When the relative abundance of the more valuable spruce is compared with that of the less valuable balsam fir, as in Figure 6, a strong tendency is evident for balsam fir to replace spruce in the spruce-flat type. The representation of spruce decreased from 56 per cent in the original stand to an average of 34 per cent in 5 to 40 year old cuttings, while that of balsam fir increased from 44 to 66 per cent. This was due primarily to the ability of the balsam to grow more rapidly after removal of the overhead cover. Its greater

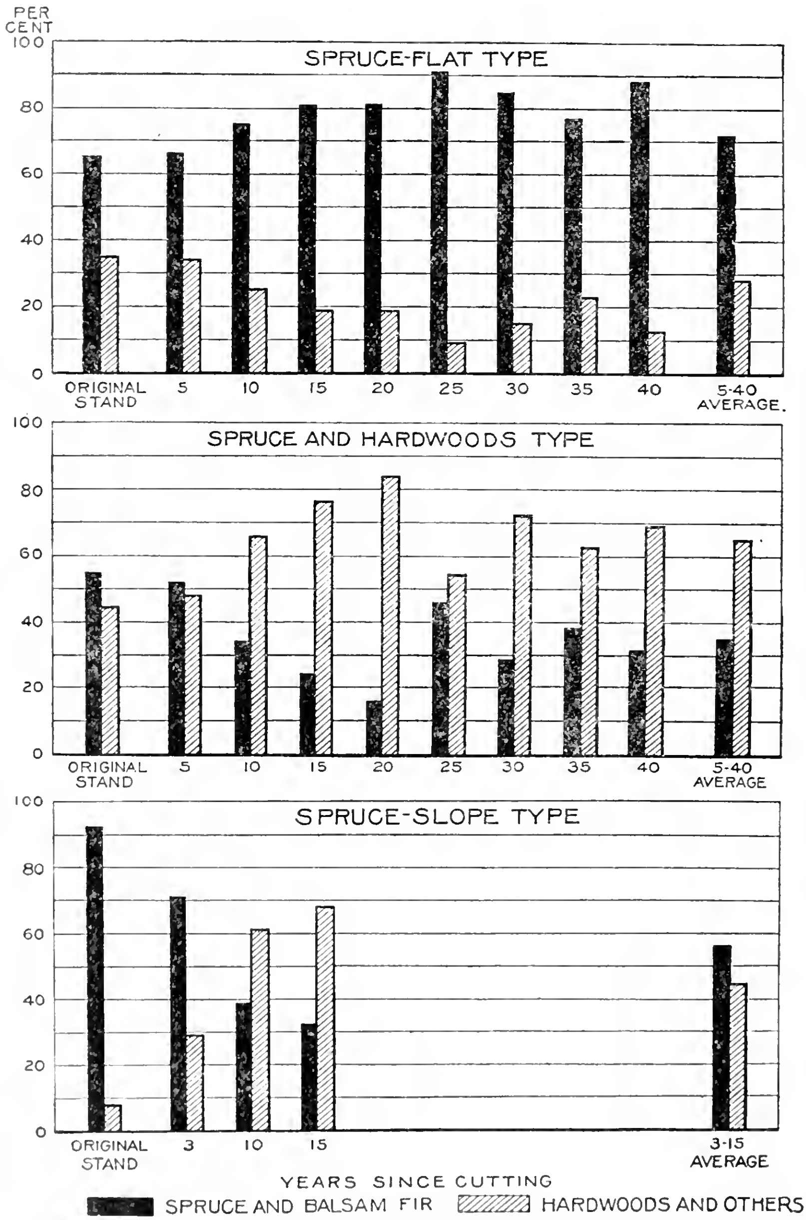

FIGURE 5.—Relative numbers of spruce and balsam fir and of hardwoods and other trees present in the original stand and at various intervals after cutting

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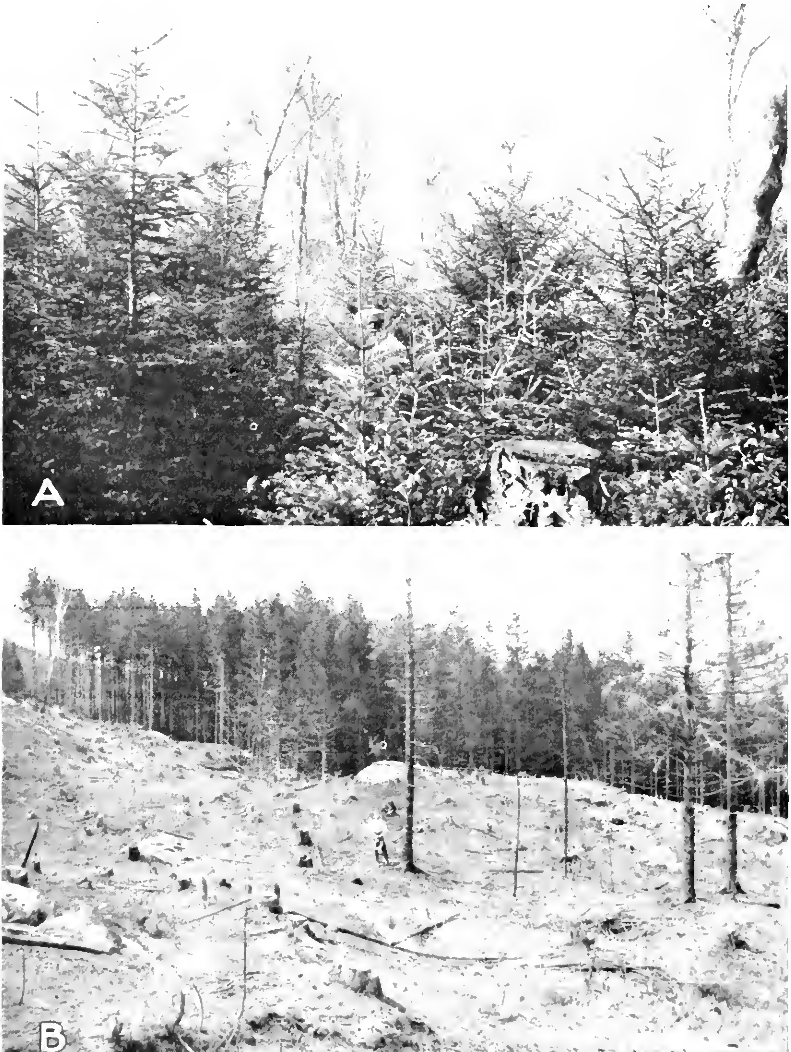
DENSE AND OPEN SPRUCE STANDS IN NEW HAMPSHIRE

A, A dense stand of merchantable spruce on the summit of a ridge. Clear cutting in such a situation as this is the only method of logging not likely to result in heavy windfall. B, an example of the old-field spruce type. Note the large number of dead branches retained by the trees in this young open-grown stand as compared with the older, denser stand shown in A.



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THE IMPORTANCE OF ADVANCE REPRODUCTION IN SPRUCE CUTTINGS

Note the abundance and vigorous growth of the spruce and balsam fir seedlings (A) after clear cutting in a stand of spruce with ample advance coniferous reproduction in contrast with the results in a stand of spruce without advance reproduction (B). Hardwoods may creep in gradually on the latter areas, but reproduction of spruce and balsam fir is unlikely. Both views are in Grafton County, N. H.

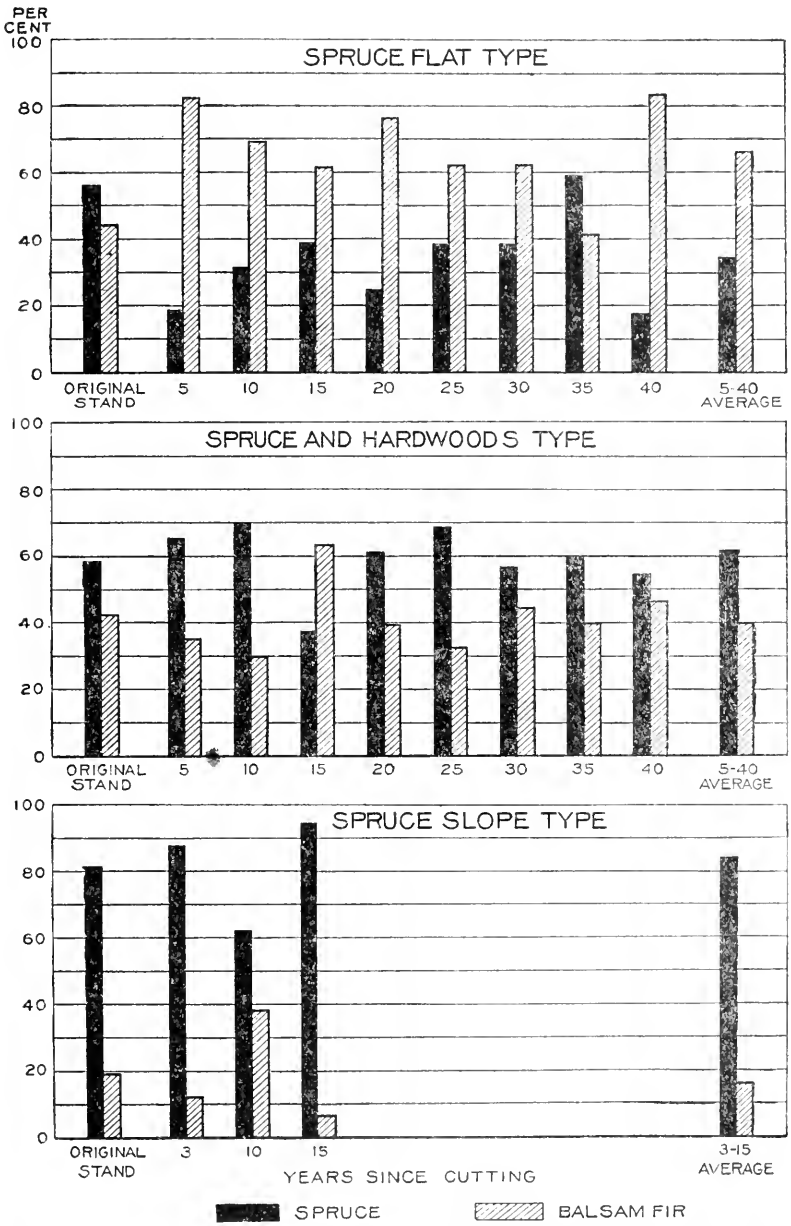


FIGURE 6.—Relative numbers of spruce and of balsam fir present in the original stand and at different lengths of time following cutting

aggressiveness leaves little doubt that balsam fir will predominate at the time of the next cutting in spite of the greater persistence and longer life of the spruce.

In the spruce-hardwood type, on the other hand, the more tolerant and persistent spruce is better able to hold its own in competition with the hardwoods. Although both spruce and balsam fir tend to be crowded out after cutting in this type, there is little danger that balsam fir will encroach to any marked degree on spruce. Spruce also maintains its much greater abundance in the spruce-slope type, where the thinner, drier soils are less favorable to the balsam fir.

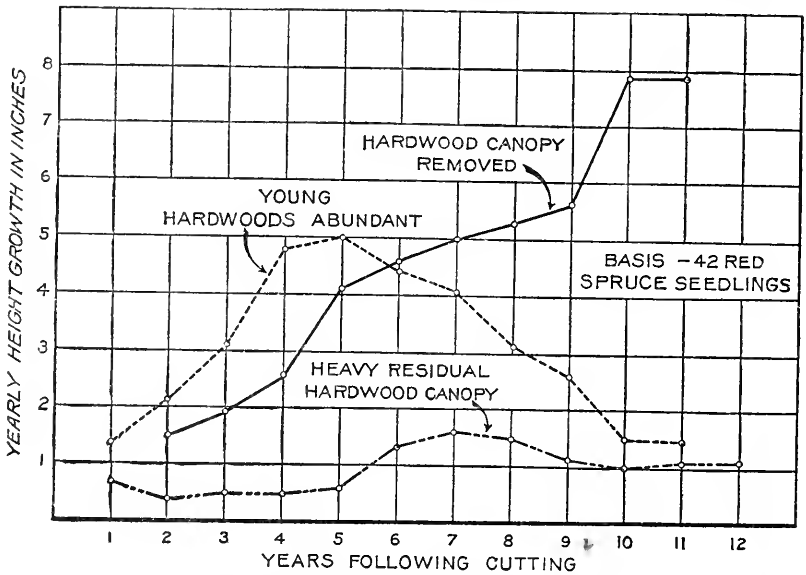


FIGURE 7.—Yearly height growth of spruce seedlings after cutting in three different conditions of hardwood competition

The growth of spruce and balsam-fir seedlings after cutting varies both with the degree of suppression and with their height at time of release. In general, the best response is from seedlings between 1 and 5 feet in height. Spruce seedlings of all sizes on cut-over areas in the spruce-hardwoods type, where the overhead cover had been entirely removed, attained an average height of 77 inches in 12 years as against 20 inches in the same time under a dense cover. Balsam fir, responding more quickly and growing more rapidly after liberation, does better than this. Both species when in mixture with hardwoods at first increase in rate of height growth and then decrease rapidly as the competition of the hardwoods makes itself felt. (Fig. 7.)

About 20 per cent of the advance growth of all species is destroyed, much of it unnecessarily, during logging operations. (Fig. 8.) The heaviest loss with spruce and balsam fir is in the seedlings which are from 1 to 5 feet in height and which because of their vigor and rapid growth form the main reliance for the next crop of pulpwood.

METHODS OF CUTTING

Whenever advanced growth is abundant in the spruce-flat type, as it usually is, clear cutting of all merchantable trees is advisable. (Pl. 8.) This will permit the maximum development of the young trees already on the ground and should result in a well-stocked new stand Often the new stand will be so dense as to retard its growth. Whether or not this is the case can be determined either from appearances or by boring into or cutting down a few trees and examining their annual rings. If in the young trees these rings are decreasing steadily in width it is pretty sure evidence that the stand is too dense and consequently is in need of thinning. By removing the smaller, poorly formed, and less thrifty trees, the crowns of the larger, more vigorous individuals can be freed and thereby given

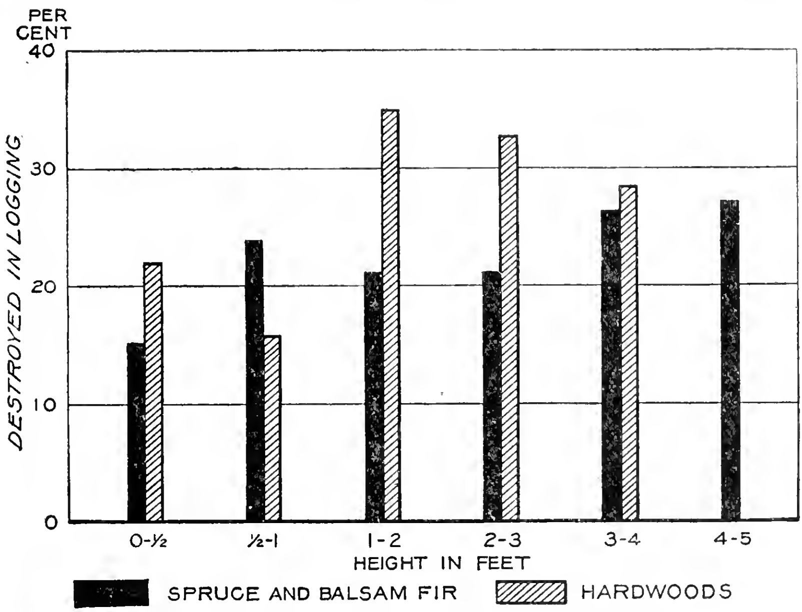


FIGURE 8.—Destruction of advance growth during logging

ample opportunity for development. Such thinnings are worth while when the material removed can be marketed with little or no loss; but it is impossible to state without further investigation how large a net outlay in thinning operations would be justified solely by the resultant increase in final returns from the timber crop.

Where advance growth is scanty, only a third to a half of the crown canopy should be removed. This will stimulate and encourage reproduction, and after the new reproduction is well established, the remainder of the stand can be cut clear. The chief objection to partial cutting aside from extra cost, which may perhaps run as high as $0.50 per cord, is the danger from windfall. Both spruce and balsam fir are such shallow-rooted species that heavy loss from this cause often follows cutting in stands with exceptionally tall trees, on areas especially exposed to the wind, or on sites with unusually shallow or moist soil. Where these conditions exist, the first cutting should remove even less than a third of the stand.

In the spruce-hardwoods type, the advance growth of spruce and balsam fir is less generally satisfactory than in the spruce-flat type. Where advance growth is plentiful, clear cutting of both conifers and hardwoods to the lowest merchantable diameter will give it the best opportunity for development. However, where yellow birch is the prevailing hardwood in the stand, the spruce and balsam fir seedlings should have an average height of about 2 feet to enable them to hold their own, and they should be at least 4 feet high where sugar maple or beech predominates. A good illustration of the competition sometimes met by the conifers is afforded by a stand on the White Mountain National Forest, which contains 13,000 sugar maple seedlings less than 5 feet high as against 900 red spruce and balsam fir. Eighty per cent of the spruce and fir are less than one-half foot in height. Under these conditions the spruce and balsam fir, although present in sufficient numbers to form a satisfactory basis for a new stand, are almost certain to be choked out by the much more abundant maple with its characteristically heavy foliage and spreading crown.

The development of the conifers after clear cutting can be greatly aided by cutting back the competing hardwoods. This is particularly necessary with maple and beech, and where these are abundant it may be the only means of retaining any considerable representation of conifers. When the spruce and balsam fir are from 3 to 5 feet in height, the hardwoods should be lopped back at a convenient height with a machete, brush hook, or hand ax wherever they are overtopping or crowding the conifers. Although not enough work of this sort has been done to prove definitely how much it will increase the growth of the conifers, relative development on areas where hardwood competition is severe and where it is naturally lacking indicates that the average growth of the conifers will increase at least 100 per cent and probably more. Experiments by a pulp company in New Hampshire indicate an average cost of about $2 an acre.

Heavy cutting of the merchantable hardwoods, or even any cutting of them at all, is often impracticable because of the impossibility of profitable marketing. When this is the case, the advance growth (and subsequent reproduction) of spruce and balsam fir will be seriously held back by the overhead shade of the hardwoods and their heavy draft on soil moisture. This competition can be reduced by girdling and killing some of the hardwoods. The girdling may be done by removing a strip of bark or cutting a shallow notch entirely around the tree. The notch, which appears to be the more effective in killing the tree, may be made most readily by two downward strokes of the ax, the second above the first.

Experiments by a pulp company in New York show a girdling cost of about 1.8 cents a tree, or $1.30 an acre, with a range from $1 to $1.75 an acre (*10*, *11*). Girdling an average of 72 trees per acre released about 400 spruce and balsam fir seedlings at a cost of 0.3 cent for each tree released. The forester in charge of the work estimates that without such release only a third of these trees would have survived and that the survivors would have taken twice as long to reach merchantable size. In a somewhat similar experiment in Maine girdling an average of 62 hardwoods an acre was estimated to cost $1.50 an acre, with resultant benefit to two spruce and balsam fir trees 5 feet or more in height for each tree girdled (*8*).

Girdling should, of course, be limited strictly to hardwoods which are actually interfering with the development of good coniferous reproduction and which, because of poor quality or inaccessibility, are practically certain to have no commercial value in the near future. The removal of "wolf" trees with widely spreading crowns is particularly important.

Where spruce and balsam fir reproduction in the spruce-hardwoods type is inadequate, as it often is in stands which have been repeatedly culled for these species, it will be difficult to obtain any considerable amount of conifers at reasonable expense by any method of cutting. Removing all merchantable hardwoods and leaving the conifers offers the best possibility. With hardwood seedlings already in possession of the ground, however, even this is of doubtful efficacy. It also has the disadvantage of exposing the remaining conifers to windfall, which, although not so serious as in the spruce-flat type, is still a factor to be taken into consideration. Stands of this sort can most advantageously be handled to favor the best hardwoods in much the same way as is suggested for the northern-hardwoods type.

In the spruce-slope type, reproduction of spruce and balsam fir is nearly always adequate. Clear cutting is therefore satisfactory and, indeed, almost compulsory because of the extreme danger from windfall on the thin-soiled exposed sites occupied by this type. Partial cutting is almost certain to result in heavy loss. The only real alternative to clear cutting is, therefore, to leave the stand intact as a protection forest. This may be advisable in the rather rare instances where reproduction is lacking. Also, and more commonly, this course may be advisable where the forest cover is of great importance in preventing erosion and regulating stream flow. Fire constitutes an exceptionally high hazard after cutting in this type, slash fires on these slopes being frequently so severe as to destroy not only the stand but even the soil itself.

In the spruce-swamp type, reproduction is usually abundant and the danger from windfall great. Clear cutting is, therefore, satisfactory and the only safe method for general use.

Clear cutting is also advisable in the old-field spruce type wherever there is an abundance of advance growth. This is ordinarily the case except in unusually dense stands, which can advantageously be removed in two cuttings. In such stands the first cutting should remove from a third to a half of the crown canopy, as recommended for the spruce-flat type. The remainder of the stand can then be cut after reproduction is well established. The old-field spruce type usually occurs on fairly deep, well-drained soils where the danger of windfall after partial cutting is not great.

Care should be taken in logging all of the spruce types to do as little injury as possible to the advance growth of spruce and balsam fir. Hardwoods, on the other hand, may be cut back freely if it is desired to favor the softwoods. Grazing of cut-over lands will also help to keep back the hardwoods and thus to give the spruce and balsam fir the advantage. It is, in fact, highly probable that the practically pure softwood stands so frequently found in the old-field spruce type are due in large part to grazing.

SLASH DISPOSAL

When any considerable volume of timber is removed, the slash left after logging is likely to be sufficiently dense over a large part of the area to interfere seriously with reproduction. Figure 9 shows the percentage of the area covered by slash after cuttings of different severity on three experimental plots in the spruce and hardwoods type in New Hampshire. Approximately 2 per cent of each

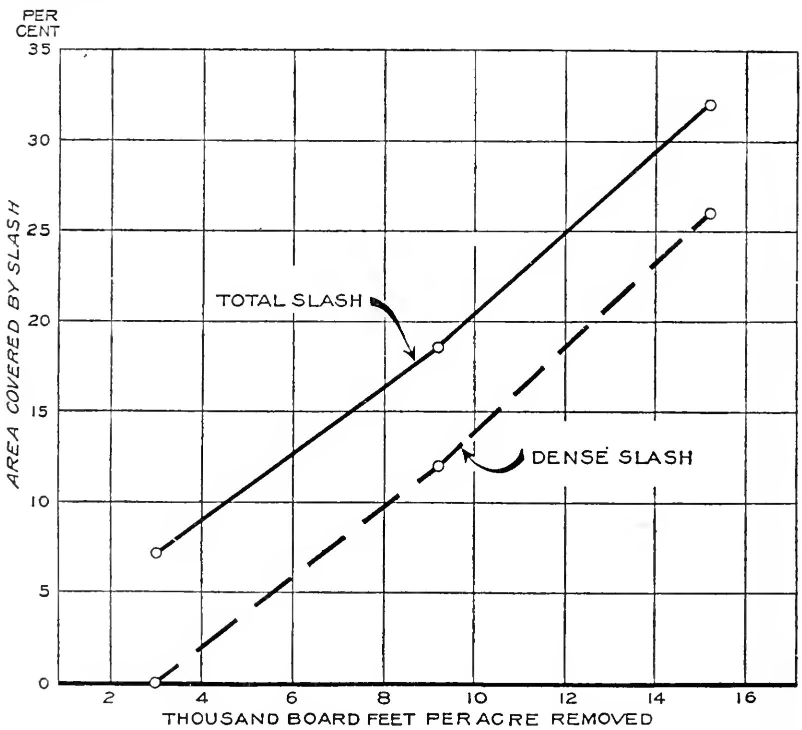


FIGURE 9.—Relation between volume cut per acre and percentage of area covered by slash in the spruce-hardwoods type

plot was covered by slash for each thousand board feet of timber removed, and the amount of dense slash varied from 0 to 81 per cent of the total. In an adjacent plot from which 8,750 board feet were removed 39 per cent of the area was covered by slash, but only 46 per cent of this, or 18 per cent of the whole, was classified as dense.

Both the total area covered by slash and the area covered by dense slash will vary not only with the amount of material cut but with the character of the stand and the way in which the slash is handled. Spruce and balsam fir, with their much smaller crowns and much closer utilization, produce considerably less slash than hardwoods. On the other hand, the conifer slash is piled much more closely. Consequently, for equal volumes of timber removed, conifers produce less total slash than hardwoods, but a considerably larger percentage of dense slash. Both facts are brought out in the figures in Table 7, which were derived from one of the plots mentioned in the preceding paragraph.

TABLE 7.—*Area covered with slash and character of slash after cutting on an experimental plot in the spruce-hardwoods type in New Hampshire*

Species	Volume per acre removed	Area covered with slash	Character of slash		
			Dense	Medium	Light
	Board feet	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Conifers	4,690	17	62	23	15
Hardwoods	4,060	22	36	33	31

Dense slash is formed by the common practice of throwing the branches together in piles or windrows, often several feet deep. This practice is regarded as essential to clear the ground for logging unless the slash is got out of the way by burning; but it is none the less detrimental to the production of full crops of timber, since a really dense pile or windrow is likely to prevent any growth on the area beneath it for as much as 10 to 20 years. The loss of spruce and balsam fir seedlings in the course of two years under slash of different densities is shown in Figure 10. If the 12 per cent which died where there was no slash represents the normal mortality of seedlings up to 4 feet in height on the plots in question, then the loss due to slash during the first two years after cutting averaged 13.5 per cent under light and medium slash and amounted to 34 per cent under dense slash. There is little doubt that under the dense slash the loss will continue until it is practically complete.

This waste of good growing space can be avoided by burning the conifer slash currently during late fall or winter logging, when there is little danger of starting a forest fire. The slash should be thrown on small burning piles as the logging proceeds. This method avoids the greater fire risk, the larger area covered by slash piles, and the higher costs, which are involved when the slash is piled at the time of logging but left for burning later. Delayed burning may, however, be the only resort during spring or summer logging when the forest floor is so dry as to render any burning dangerous. In that case, the piles should be not more than 6 feet high or 8 feet in diameter, and should be placed where their subsequent burning will result in as little damage as possible to the adjacent reproduction and larger trees. The burning can be done in the late fall or early winter, when heavy rains or snows have made this safe.

Burning as the logging proceeds will, of course, kill all tree growth on the spots actually covered by the piles; but since relatively few piles are needed, these spots need not exceed 1 per cent of the total area. The cost will probably vary from $1 to $1.50 for each thousand board feet of conifer timber cut. The method is now in general use only on the White Mountain National Forest. Nevertheless, its advantages in increasing the space available for forest production, in decreasing the fire hazard, and possibly in reducing the danger from insects and disease, commend its adoption wherever logging will result in covering any considerable part of the area with dense slash.

Burning hardwood slash is more difficult and less necessary. It does not form such dense piles as the conifers, and in the spruce types seldom covers a large percentage of the area so completely as to interfere seriously with the establishment of a new stand. Although its removal would be beneficial in the occasional instances where such interference does exist, burning would probably cost more than it is worth.

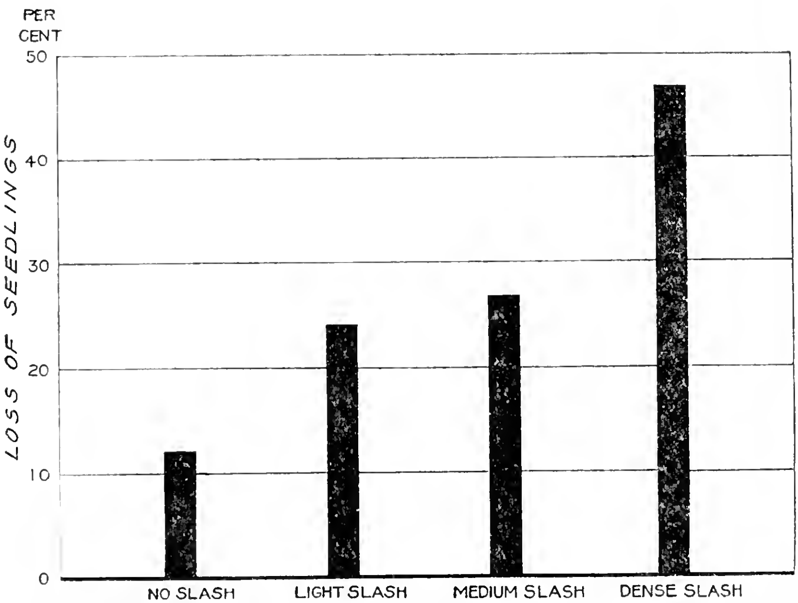


FIGURE 10. Loss of spruce and balsam fir seedlings under slash of different densities, 1923–1925

PROTECTION FROM INSECTS

Both spruce and balsam fir are subject to serious injury from defoliation by larvæ of the spruce bud worm (*Cacoecia fumiferana*). This is a native insect which at more or less irregular intervals has caused tremendous loss. In Maine, for example, during the epidemic from 1910 to 1920 it destroyed two-fifths of the merchantable stand of spruce and balsam fir (*35*).

Outbreaks almost invariably start where an abundant supply of balsam fir, the favorite food plant of the bud worm, enables the insects to propagate in sufficient numbers to attack also the spruce. It is therefore important to check so far as practicable the tendency of this species, particularly in the spruce-flat type, to increase its representation at the expense of the spruce. This can be done to some extent by removing as much balsam fir as possible when partial cuttings are made in mature stands or thinnings in young stands. Early utilization of stands with a large percentage of balsam fir will also help, since it is the older trees with crowns well exposed to the sun which are most severely attacked.

Aside from reducing the proportion of balsam fir, the only hope of preventing bud-worm epidemics seems to lie in cutting out infestations the moment they appear. By training foresters and woodsmen to recognize bud-worm injury in its early stages and by keeping a sharp lookout for its presence, it should be possible to locate places where the bud worm is increasing abnormally before the infestation has reached serious proportions. The infestation in these places can then be checked either by putting in a pulpwood operation or, where this is not possible, simply by felling or girdling the affected trees. This will dry out the foliage sufficiently so that the bud worms will die. Unless infestations should spring up simultaneously over a very wide area, it should be possible in this way to hold the insect in check and to prevent the recurrence of any such destructive epidemic as the last one in Maine.

The eastern spruce beetle (*Dendroctonus piceaperda*) is another insect which in times past has caused heavy damage. During recent years, however, losses from it do not appear to have been serious, and its principal activity has ordinarily been in trees already weakened by the bud worm or some other agency. The damage is done by the larvæ, which girdle the trees by working in the inner bark. The insect may be controlled by cutting out the affected trees and putting them in water.

YIELDS [6]

The Northeastern Forest Experiment Station has recently measured some 400 sample plots and obtained the yields from fully-stocked, even-aged stands of red spruce as shown in Table 8 for the ages indicated.

The three sites represent good, average, and poor growing conditions, and do not include either the very best or the very worst. More specifically, good sites are taken as those on which the average dominant and codominant trees (i. e., the taller trees in the stand) reach a height of 60 feet in 65 years; average sites are indicated by a height of 50 feet at the same age, and poor sites by a height of 40 feet. Although the plots measured were largely in the old-field spruce type, the yields in other types should average approximately the same if the same criterion of site is used.

TABLE 8.—*Yields per acre of fully stocked, even-aged stands of second-growth red spruce in the Northeast; basis, 400 plots*

Age (years)	Good site		Average site		Poor site	
	Peeled pulpwood volume	Saw-log volume	Peeled pulpwood volume	Saw-log volume	Peeled pulpwood volume	Saw-log volume
	Cords	*Board feet*	*Cords*	*Board feet*	*Cords*	*Board feet*
40	17.4	2,200	11.7	1,200	6.3	0
50	39.7	9,900	29.1	6,200	17.6	2,800
60	58.4	20,800	44.2	13,300	29.0	5,800
70	69.7	31,800	54.2	20,300	36.5	8,800
80	76.6	38,900	60.0	24,800	41.3	10,800
90	80.5	42,800	63.2	27,400	43.8	11,900
100	82.8	45,100	65.2	28,800	45.4	12,600

[6] The material in this section is taken from a very detailed report by W. H. Meyer, now at the Pacific Northwest Forest Experiment Station (32). Grateful acknowledgment is made to Mr. Meyer for permission to use his material in this connection.

The cord volumes shown were obtained by converting into cords the cubic-foot contents of all trees with a breast-high diameter of 4 inches or more, from a 1-foot stump to a top diameter of 3 inches inside bark, exclusive of butt swell, on the basis of 95 cubic feet of solid wood to a stacked cord (peeled) of 128 cubic feet. The total volume of single trees with bark averages about 12 per cent higher than the same wood peeled. Since unpeeled bolts fit less closely than peeled an overrun of at least 15 per cent should probably be allowed in determining the solid contents of stacked cords of unpeeled wood. The board-foot volumes were obtained by scaling all trees with a breast-high diameter of 7 inches or more, from a 1-foot stump to a top diameter of 5 inches inside bark, in 16.3-foot logs, by the

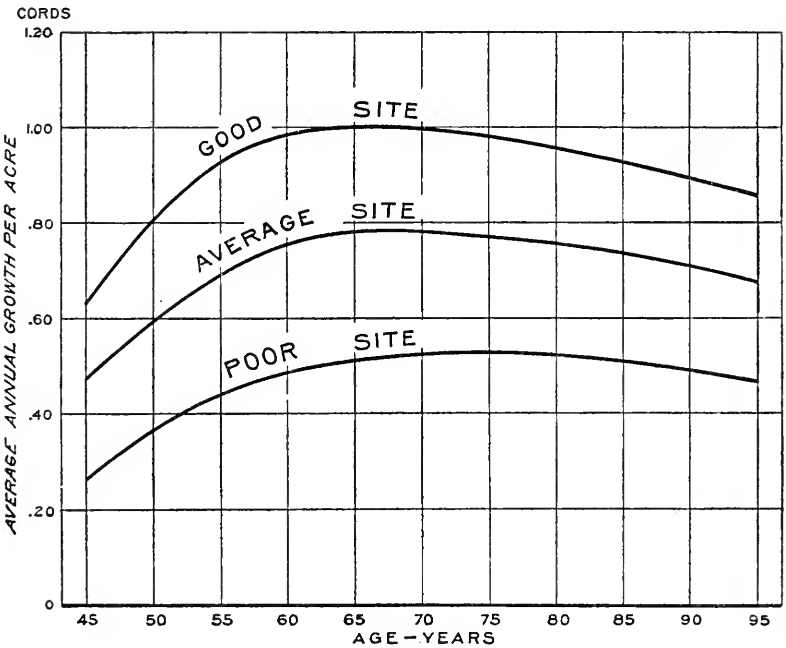


FIGURE 11.—Mean annual growth of fully stocked stands of second-growth red spruce in cords per acre

international rule with ⅛-inch saw kerf and with no allowance for cull.

Total age was determined by getting the age at breastheight and adding 15 years to allow for the period necessary to reach this height. In applying the figures given, the total age of the stand in question should be determined in the same manner, or by adding 7 years to the age as indicated on a 1-foot stump. Theoretically this period should not be the same for all sites, but a number of measurements of thrifty seedlings that had ample room for growth failed to show any consistent difference in this respect. It is evident that the influence on seedling development of the broad site classes recognized in the preparation of yield tables is somewhat obscured by local variations in soil conditions and competing vegetation.

which may be of minor importance to older trees but are of major importance to the young seedlings.

The mean annual growth at different ages is shown in cords of peeled pulpwood in Figure 11 and in board feet of saw-log material in Figure 12. For average sites pulpwood reaches its maximum at 65 years, saw timber at 82 years. To produce the greatest amount of high-quality lumber, however, would undoubtedly require considerably longer than 82 years, since natural pruning of spruce does not take place at an early age.

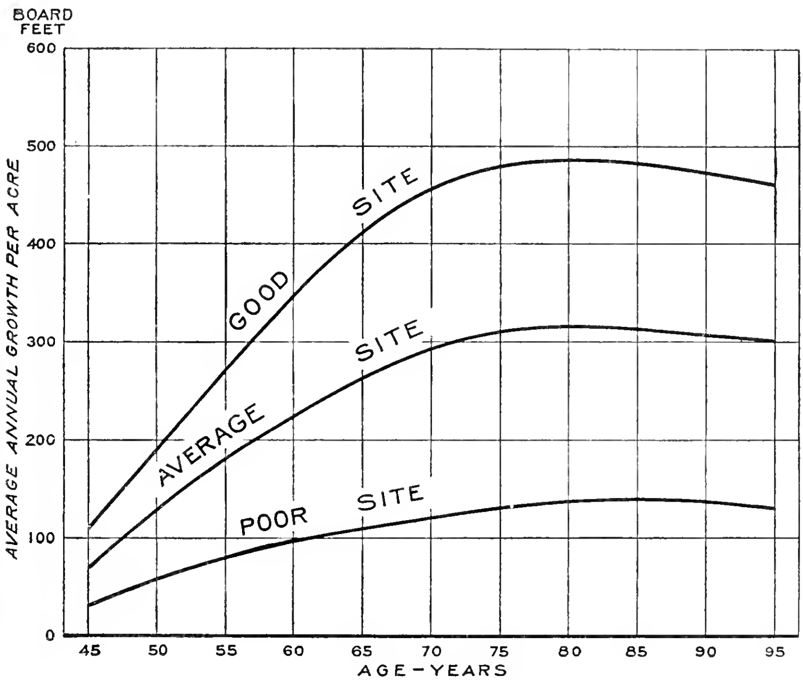


FIGURE 12.—Mean annual growth of fully stocked stands of second-growth red spruce in board feet per acre

The annual growth of pulpwood material as measured at 10-year intervals reaches its maximum at about 45 years, and the annual growth of saw-log material at 60 years. At these ages the periodic annual growth is as shown in Table 9.

TABLE 9.—*Periodic annual growth of pulpwood and saw-log material in their respective years of maximum periodic annual growth*

Product	Good site	Average site	Poor site
Pulpwood material in cords per acre at 45 years	2. 23	1. 74	1. 13
Saw log material in board feet per acre at 60 years	1, 160	740	325

The mean annual growth of more than four-fifths of a cord per acre on average sites and of more than 1 cord per acre on good sites, which is reached at 65 and maintained up to 75 years of age, indicates that the possible yields of pulpwood from red spruce are much higher than has been generally believed. The yields shown are particularly striking in view of the extremely slow seedling growth—15 years to breastheight. They occur, of course, only in fully stocked stands and are, therefore, not found over the considerable area of poorly stocked stands which make up the bulk of the present forest. They do, however, serve to indicate the possibilities, and could doubtless be increased under an intensive management which included one or more thinnings.

Yields of saw-log material, which on average sites amount to only 17,050 board feet at 65 and to 22,900 board feet at 75 years of age, with a mean annual growth of only 260 and 310 board feet, are much less satisfactory than the yields of pulpwood material. The difference is due to the fact that fully stocked stands of red spruce maintain a high density with a correspondingly small average diameter. The figures in Table 10 show for red spruce the number of trees per acre and the average diameter at 65 years of age on an average site.

TABLE 10.—*The number of red-spruce trees per acre and the average diameter at 65 years of age, average site*

Stand	Trees per acre	Average diameter
	Number	*Inches*
Total stand	980	6.5
Trees 4 inches d. b. h. and up	897	6.7
Trees 7 inches d. b. h. and up	390	8.2

Partially stocked stands approach a more fully stocked condition with advance in age. They usually average larger in diameter than fully stocked stands and contain a volume that is relatively high in proportion to the number of trees. This is particularly true of board-foot volume, which reaches its maximum with about 65 per cent of the number of trees needed to produce the pulpwood maximum. There is little doubt that in dense stands larger yields could be obtained in a shorter time by judicious thinnings, thus keeping the stands well stocked without overcrowding.

Mixed stands consisting chiefly of red spruce, with a scattering of white spruce and balsam fir, have practically the same yields as pure stands of red spruce. Both white spruce and balsam fir grow faster than red spruce in height, but are unable to maintain so complete a crown canopy. Balsam fir stands especially seem to break up after the early ages are passed, particularly on the poorer sites. For these reasons, although pure stands of white spruce or of balsam fir show larger yields in both cords and board feet in the early years, at approximately 60 years of age they are surpassed by red spruce. Balsam fir similarly shows a tendency to exceed white spruce up to about the same age, when the latter takes the lead.

NORTHERN HARDWOODS TYPE

The northern hardwoods type is common throughout the spruce and northern hardwoods region, where it ranks with the spruce types in area. Its commercial importance is usually high when near to good markets and low when at a considerable distance from them. River driving is more difficult than with conifers, because of the greater weight of the hardwoods which makes it impossible, without special treatment, to float them far. In the less settled parts of the region, where other means of transportation are lacking, many stands of intrinsically valuable timber can not be utilized profitably because of the cost of getting the product to market.

The type chiefly occupies moist but well-drained slopes and benches of medium elevation and all aspects. The soil is usually a sandy or clay loam of moderate depth. It is more fertile than most forest land, and where the slopes are not too steep nor the stones too abundant much of it is suitable for farming. The potato district of Aroostook County, Me., consists almost wholly of land formerly covered by the northern-hardwoods type.

Yellow birch, sugar maple, and beech are the most common and characteristic species. White ash and basswood are sometimes abundant locally, as, for example, in parts of the Green Mouutains in Vermont. Red maple, hemlock, spruce, balsam fir, and white pine are usually present in varying amounts, with more or less paper birch in New England and sweet birch and black cherry in New York and Pennsylvania. (Pl. 9.) Repeated culling of spruce and balsam fir in the spruce-hardwoods type has often reduced the representation of these species so greatly as to convert many areas of originally mixed forest into the northern hardwoods type.

Virgin and culled stands in the latter type are typically uneven aged. "Wolf" trees with poorly formed trunks and widely spreading crowns are nearly always present and occupy a space out of all proportion to their value. Defect is also common, particularly in the butt logs. Second-growth stands, on the other hand, are typically even aged and are usually well stocked with thrifty young trees, although they are likely to contain more "weed" species, such as striped maple, aspen, and pin cherry, than do virgin stands.

NATURAL REPRODUCTION

Most of the species characteristic of the northern hardwoods type reproduce themselves readily. Large crops of seed are borne annually by yellow birch and sugar maple, and moderate quantities by basswood. At intervals of several years large crops are borne by white ash and small crops by beech (*21*). The seed of all five species is moderately fertile and germinates as well on humus as on mineral soil. Yellow birch often comes up quickly on burned areas. Beech and sugar maple will persist for many years under heavy shade. Yellow birch, basswood, and white ash require more light, but as seedlings they are sufficiently tolerant to thrive under a medium cover.

Because of these characteristics, seedling reproduction is ordinarily good under the more or less broken cover of the original forest.

Representation of the different species varies rather widely with the composition and density of the stand and with soil conditions. Sugar maple and beech predominate in very dense stands; white ash and basswood are common only on the better soils. Yellow birch is the least exacting in its requirements and is usually well represented where seed trees are present and where it is not crowded out by the more tolerant species.

Sprouts spring abundantly from most hardwood stumps of small or medium size. Those from larger stumps when present at all are seldom thrifty, except for basswood, which is able to produce sprouts that grow to log size from stumps as large as 2 or 3 feet in diameter. Beech sprouts rarely attain merchantable size. Sprouts from yellow birch, sugar maple, and white ash stumps less than 6 inches in diameter are usually vigorous but inferior in ultimate size and quality to seedlings. Sprout reproduction is unimportant in virgin or culled forests, but is generally abundant in second-growth stands (*21*).

METHODS OF CUTTING

Old growth and culled forests can be handled either by clear cutting or partial cutting. Clear cutting is, however, seldom practicable except where there is a ready market for fuel wood, acid wood, or small-sized material suitable for the manufacture of turned products. Elsewhere, the amount and quality of the lumber obtainable from the smaller trees is so low as to prevent their profitable utilization.

Clear cutting has the advantage of removing the competition of the mature trees for light and soil moisture, and thus giving ample opportunity for development to the abundant natural reproduction that is usually present. (Pl. 10, A.) It also favors particularly the more valuable white ash, basswood, and yellow birch, all requiring more light than either sugar maple or beech in order to make their most rapid growth. Clear cutting has the disadvantage of removing the immature trees which should be left for further growth and of creating a large amount of slash, which may retard, deform, or even kill a considerable number of seedlings. No attempts have been made, however, to burn hardwood slash, for in spite of its abundance it is so much less dense and decays so much more quickly than coniferous slash that the high cost involved in burning is hardly justified. Lopping of the slash, unless it is well scattered, is of no particular benefit to the seedlings, and even then is of doubtful value.

In clear cutting, the entire stand should be removed as completely as possible, including the small saplings. When weak and sickly, these are of little prospective value, are subject to serious injury by wind, snow, and ice, and are apt to interfere with the development of the more thrifty young growth; and when strong and vigorous they are likely to cause even greater interference by developing into " wolf " trees. Seedlings up to an inch or two in diameter should, however, be protected as carefully as possible from unnecessary damage, since it is these that form the basis for the next crop (*21*).

Partial cutting of old-growth stands, which in many localities is now enforced by economic conditions, produces material of higher average value than does clear cutting. A recent experiment in the northern hardwoods type in the Lake States (no similar figures are available for the Northeast) showed that logs from a partial cutting, which removed few trees less than 22 inches in diameter, averaged $28.93 per thousand board feet in value as against $19 per thousand from an adjacent clear cutting. The partial cutting removed about half of the value of the original stand, but left two-thirds of its volume in the form of 181 trees per acre.

In the Northeast the cutting of merchantable trees down to an average diameter of about 12 to 15 inches is advisable. All "wolf" trees should be removed, in spite of the fact that they are apt to contain a large amount of defective material; if left they will interfere seriously with the development of the young stand. A few well-formed, thrifty trees above the diameter limit may well be left for seed production and those of the more valuable species, such as white ash or basswood, for further development. Poorly formed, suppressed, or unhealthy but still merchantable trees of all species below this diameter should be cut, as should also smaller trees of the less valuable species, such as beech. (Pl. 10, B.) Special pains should also be taken to remove individual trees or groups of trees which are suppressing advance growth of desirable species.

Avoidance of logging damage to reproduction and to thrifty trees of sapling or pole size is imperative.

Partial cutting of old-growth stands has the advantage of encouraging natural reproduction, and to some extent of influencing its composition, in stands where adequate advance growth is not already present. The relatively small amount of slash produced causes little injury to reproduction. Sufficient light is admitted to stimulate the growth of trees of all sizes in the remaining stand. And finally the larger saplings are not cut just at the time when their growth is at its height and when they are beginning to put on wood of higher quality.

An important disadvantage of partial cutting is the increased danger to the remaining stand from wind, sun, snow, ice, and insects. After even a moderately heavy cutting, the trees left are apt to become stag-headed as a result of drying out or of insect attacks. The bronze birch borer (*Agrilus anxius*) is a particularly dangerous enemy of yellow birch and paper birch, and the maple borer of sugar maple. Since both insects thrive best in trees exposed to full light, damage by them is usually severe wherever partial cutting is fairly heavy. On the other hand, too light a cutting has the disadvantage of stimulating but slightly the development of the younger seedlings, particularly of the more valuable species.

The old-growth stand left after the first cutting may later be cut clear, preferably when the bulk of the trees are large enough to furnish material of good quality but before they are so large as to interfere seriously with the development of the new crop. On the other hand, partial, or selection, cuttings may be continued indefinitely, and this course offers the opportunity of improving the composition of the stand by favoring the better individuals and species at each cutting. This is particularly important when such cultural operations as the clearing and thinning of young stands are impracticable.

Second-growth stands are, as a rule, near enough a market to permit complete utilization, and have in fact, usually resulted from an earlier clear cutting. They are characteristically even aged, and when well stocked have a rather uniform, dense crown cover which prevents an advance growth of young seedlings from coming in as abundantly as in the original forest. In such stands, reproduction after clear cutting is likely to be chiefly from sprouts. These grow rapidly at first, but, with the possible exception of basswood, are less desirable than seedlings, particularly from stumps larger than 6 inches in diameter.

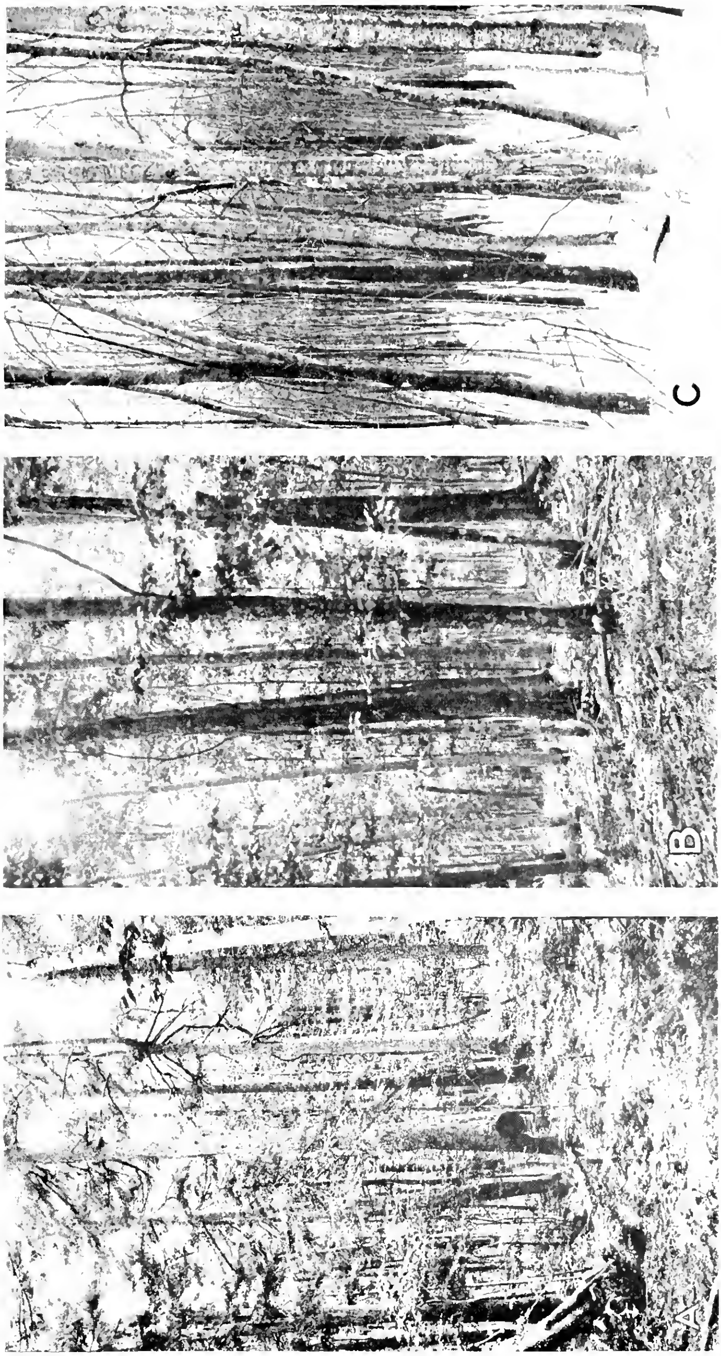
In even-aged stands without ample advance growth, best results will be obtained by a first cutting which removes about half of the volume. Well-formed, thrifty trees of the species which it is desired to favor (ordinarily white ash, basswood, and yellow birch) should be left, and other species cut as heavily as possible. Poorly formed, suppressed, and diseased trees of all species should be taken. This first cutting will open up the stand sufficiently to induce good seedling reproduction of the species favored. The remainder of the stand can then be cut clear after the new crop is well established, or removed in a series of partial cuttings. Seedlings of all the northern hardwoods will grow well for a while under light to moderate shade, but for their best development the second cutting should ordinarily be made within 10 years.

Sprouts will, of course, spring up after both cuttings. The first lot, however, will be held back by the overhead shade of the trees left, and by the time of the second cutting the seedlings should be large enough to hold their own with both lots. The final stand will then consist of a more or less even mixture of sprouts and seedlings.

The proportion of seedlings can be increased and the composition of the stand improved by cleanings similar to those described for the spruce-hardwoods type. These should be made when the seedlings are from 2 to 5 feet high. Seedlings of desirable species should be favored by cutting back both competing sprouts and seedlings of less desirable species. In order to obtain a fully stocked stand, it will nearly always be necessary to leave a fair proportion of sprouts, but these will do best if they are so thinned out as to leave only one straight, vigorous sprout to each clump.

The cost of such cleanings will ordinarily range from $2 to $4 per acre. Whether they will pay depends on the extent to which they are likely to increase the representation of the better species and consequently the stumpage value of the final stand. They should prove a profitable investment in stands located near good markets and containing valuable species that are likely, if unassisted, to be choked out by much less valuable trees.

Thinnings can also be used to advantage in older stands to favor the better species and to increase the rate of growth. Stands that start with a sufficient stocking to produce straight trees of high quality soon become too dense for their best development. When this point is reached, they can be greatly helped by thinning out the poorer individuals and less valuable species so as to give those that are left ample room for growth without opening up the stand so much as to waste space and to let in an undergrowth of grass and weeds. Thinnings can well start as soon as the trees removed are large



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TYPICAL STANDS IN THE NORTHERN HARDWOODS TYPE

A, B, Advance reproduction of both conifers and hardwoods is coming in amply; C, a young stand of second-growth yellow birch.

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CLEAR CUTTING AND THINNING OPERATIONS

A, Clear cutting for acid wood in the northern hardwoods type in Warren County, N. Y. Good reproduction from both seedlings and sprouts usually follows such cuttings; B, removing the inferior trees for fuel in a young stand in the northern hardwoods type in Rutland County, Vt. The remaining trees will develop more rapidly as a result of the thinning.

enough to cover the cost of the operation, and can be repeated whenever the stand becomes so dense as to result in decreased growth. They are not at present practicable throughout a large part of the type, but in accessible locations near to good markets may yield a substantial profit from the sale of the material removed.

Grazing of all sorts is highly injurious to hardwood reproduction, and should not be permitted in either old-growth or second-growth stands. Farmers desiring to raise both trees and livestock will find that they can do so most profitably by fencing the woodlot and by clearing up a piece of better land for exclusive use as pasture.

YIELDS

Old-growth forests in the northern hardwoods type, because of the large proportion of overmature and defective trees, are usually putting on little or no net growth. It is, therefore, advisable to put the land in a productive condition by removing the older trees and increasing the representation of younger, vigorously growing trees at the earliest opportunity.

The yield of second-growth stands varies with the site, the degree of stocking, and the relative abundance of the different species. Measurements in Vermont (*24*) of a large number of even-aged stands with the trees fairly uniformly spaced and without large openings gave the results shown in Table 11.

TABLE 11.—*Yields of well-stocked even-aged stands of second-growth in the northern hardwoods type, Vermont* [1]

Age (years)	Volume on good sites			Volume on average sites			Volume on poor sites		
	Cordwood	Saw logs plus cordwood		Cordwood	Saw logs plus cordwood		Cordwood	Saw logs plus cordwood	
	Cords	*Board feet*	*Cords*	*Cords*	*Board feet*	*Cords*	*Cords*	*Board feet*	*Cords*
20	17.4			14.4			10.9		
30	25.6			20.8			15.6		
40	33.3	3,500	24.1	26.7	2,000	21.2	20.2	1,000	17.1
50	39.9	9,900	22.9	32.8	4,500	22.9	24.4	3,000	21.2
60	45.3	13,800	20.6	36.5	8,200	22.6	28.1	6,600	17.6
70	49.5	15,100	18.8	40.0	10,900	20.6	31.2	9,100	16.2

[1] For composition of stands see text.

Cord volumes include the contents of the main trunk plus limb wood. They were first determined in cubic feet and then converted into cords on the assumption that there are 85 cubic feet of solid wood in a stacked cord of 128 cubic feet. Board-foot volumes were obtained with the Vermont rule by scaling all logs that were 6 inches or over in diameter at the top end, whether merchantable or not. Since many of the larger hardwoods are defective, the volumes shown must be reduced in accordance with the defect present in order to get the wood that could actually be sawed out.

The stands measured represented better than average conditions, but were not fully stocked and do not indicate the maximum obtainable. Their average composition was as follows:

Sugar maple	45 per cent	Beech	8 per cent
Yellow birch	18 per cent	Basswood	3 per cent
White ash	10 per cent	Others	16 per cent

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The mean annual growth of these stands in cords and in board feet is shown in Figures 13 and 14. It is rather surprising that the maximum growth in cords should have been reached as early as at 20 years of age. This would seem to indicate that the stands, in spite of the fact that they were not regarded as fully stocked, must have been too dense in places at least, and that the rate of growth might have been maintained by judicious thinning. This is still more true of the growth in board feet, which reached the rather low maximum of 230 feet on site 1 at 60 years of age.

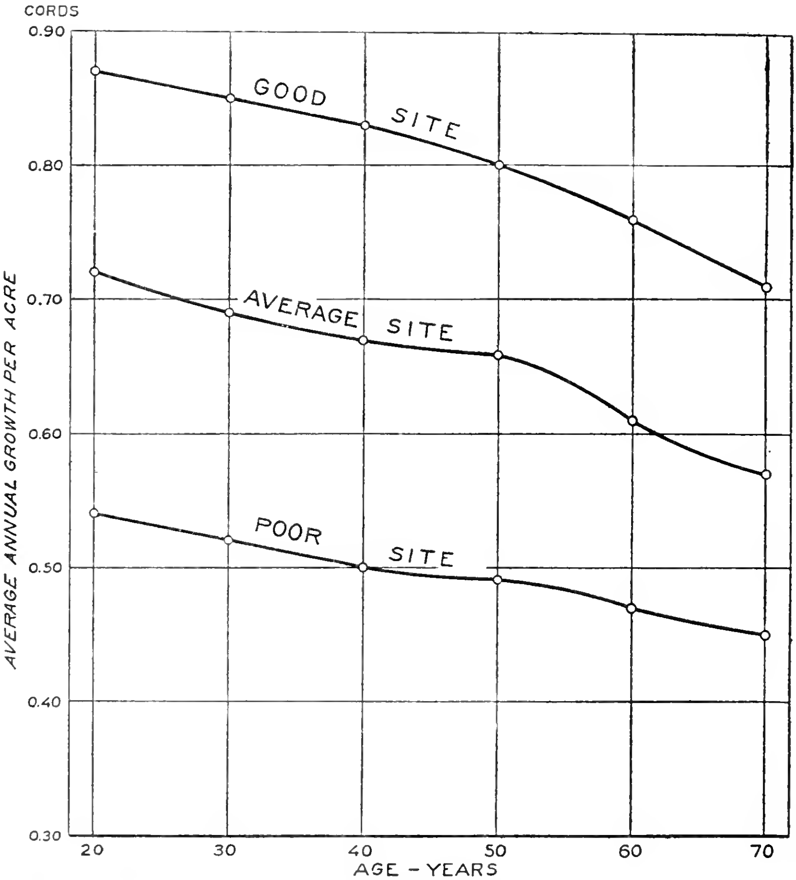

FIGURE 13.—Mean annual growth in cords of fully stocked, even-aged second-growth stands of northern hardwoods in Vermont

Additional information on yields under average conditions (*21*) is given in Table 12, which presents measurements of sample plots in well-stocked second-growth stands selected at random in other States. The cord volumes show merchantable fuel-wood material in trees 3 inches and over in breast-high diameter to a top diameter of about 2 inches, and were obtained by dividing cubic-foot volumes by 85. The crown density is shown in tenths, perfect density being 1. The crown density of birch, however, is seldom greater than 0.9, which may be considered perfect for that species.

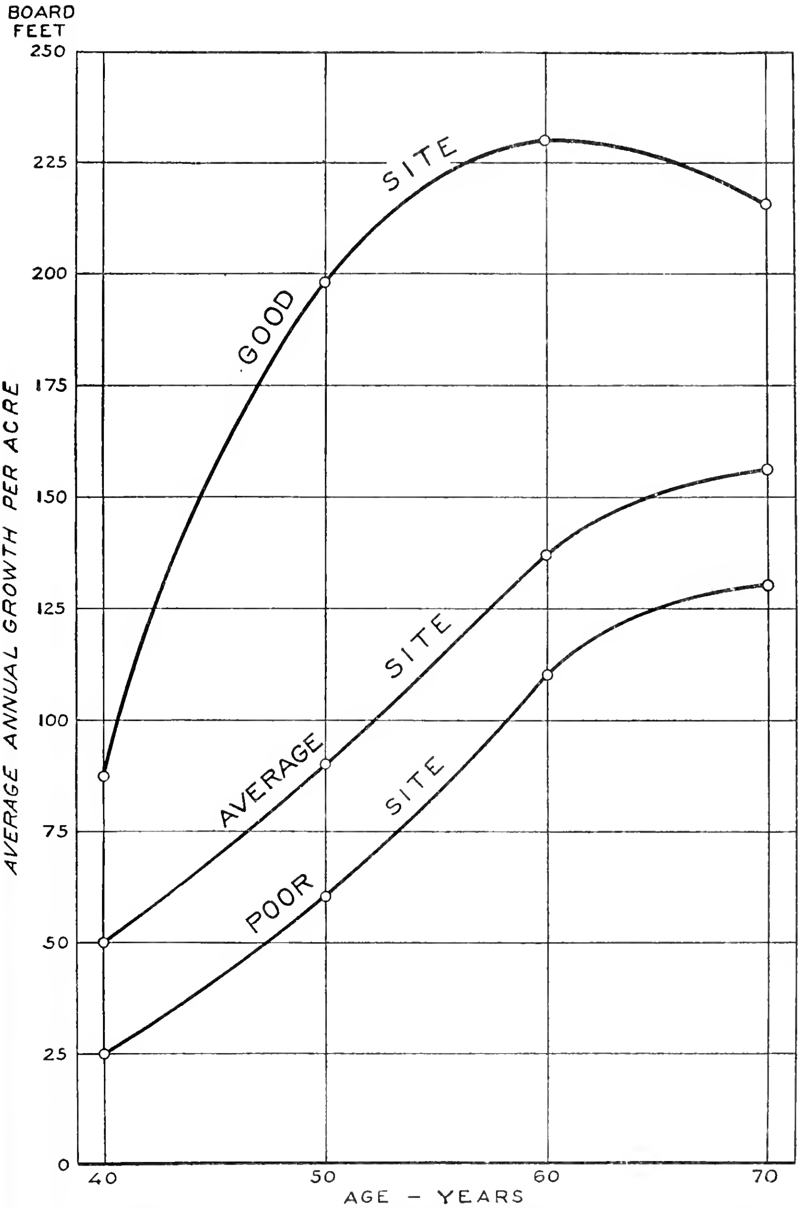

FIGURE 14.—Mean annual growth in board feet of fully stocked, even-aged second-growth stands of northern hardwoods in Vermont

TABLE 12.—*Yields of well-stocked second-growth stands of hardwoods in several States in the Northeast*

Location	Principal species and predominance in stand		Age	Crown density	Volume per acre	Mean annual growth per acre
		Per cent	*Years*		*Cords*	*Cord*
New Hampshire	Yellow birch	88	43	0.8	24.2	0.60
Do	do	78	75-80	.9	22.9	.29
Do	do	64	88	.9	38.6	.44
New York	do	56	20	.9	10.8	.54
Do	do	54	42	.7-.8	25.8	.61
Do	do	51	42	.9	30.6	.73
Pennsylvania	do	76	50	.85	10.9	.22
Do	do	85	80	.9	42.2	.53
New York	Sugar maple	78	39	1.0	28.0	.72
New Hampshire	Beech	58	70	.85-.9	22.9	.33
Do	do	92	95	1.0	33.1	.35

Recent studies in northern Pennsylvania indicate an average yield of about 1 cord per acre per year in fully stocked stands between 25 and 50 years of age (*26*). After 60 years the total volume increases very slowly. These yields are considerably more than can be expected under natural conditions over large areas, but are not unreasonable on good sites under intensive forestry.

BIRCH-ASPEN TYPE

Although the birch-aspen type is of minor importance in comparison with the types already discussed, it occupies a considerable area in the spruce and northern hardwoods region. It is most common in northern New England, where it is the chief source of paper birch for spools and other turned products and of aspen for pulpwood. Either of these characteristic species may form pure stands, or they may occur together in practically every degree of mixture. Pin (fire) cherry is often present, and there is sometimes a sprinkling of other hardwoods, notably yellow birch.

In New York and Pennsylvania the type is of decidedly minor importance in this region, both geographically and commercially. Paper birch is often entirely lacking, and pin cherry is a common and typical associate of the aspen.

Paper birch and aspen are both decidedly intolerant of shade and are able to establish themselves only on mineral soil. As a result they are poorly represented in the original forest. On the other hand, the exposed mineral soil and the absence of vegetation which are characteristic of freshly burned areas offer ideal conditions for reproduction, and the fact that both paper birch and aspen produce each year large quantities of very light seeds which are blown by the wind to great distances enables them to take prompt advantage of these conditions. For these reasons the type is not only common on burned-over lands, but is practically confined to them. It occasionally comes in on clear-cut areas where the mineral soil has been largely exposed by logging, but on such areas includes a much greater mixture of other species than is characteristic of burns.

Both species will grow on a wide variety of soils, although they thrive best on those of good quality. In Maine, for example, a

31-year-old aspen stand (*49*) on deep, loose, sandy loam had 672 trees per acre about 60 feet high and from 6 to 8 inches in diameter, while on a dry, gravelly ridge less than 10 rods away another stand of the same age had 1,224 trees per acre that averaged only about 25 feet in height and from 2 to 5 inches in diameter. On the poorest sites, particularly where the soil has been severely burned, some stands never attain merchantable size.

Because of the way in which it originates, the type always occurs in the form of even-aged stands. The light foliage of the trees and their inability to stand much crowding or overhead shade result in a comparatively light cover under which the more tolerant species reproduce readily. There is, therefore, nearly always an understory of spruce and balsam fir or, on the better soils, of sugar maple and yellow birch. These thrive under the light shade and eventually take possession of the area. Under natural conditions the type is thus a strictly temporary one. It serves a valuable purpose in reclothing burned land which might otherwise lie idle for a considerable period, but it is unable to perpetuate itself in competition with more tolerant and more persistent species.

METHODS OF CUTTING

Ordinarily, the owner of land in this type is glad to let it revert to the species which are naturally taking possession. Where this is so, all that is necessary is to clear cut the paper birch and aspen and thereby give the understory a chance to develop. (Pl. 11.) It is important, however, that the cutting be done before the stand is more than 70 or 80 years old, for older trees suffer badly from heart rot. A 95-year-old stand of aspen in Maine (*49*) had 8 cords per acre in standing dead trees, 3.4 cords in living but unsound trees, and 5.7 cords in sound trees. At least half of the wood in the unsound trees was probably so decayed as to be unmerchantable. If so, only 43 per cent of the total stand of 17.1 cords was still sound enough to be of any value. In an adjacent stand of the same age and running 32.9 cords per acre, cutting permitted a more accurate estimate; here the defect was 53 per cent.

If the stand is fully stocked, however, an earlier partial cutting preceding the clear cutting will save much material that would otherwise be lost. Because of the inability of paper birch and aspen to endure crowding, the mortality in such stands is high; also, the rapid decay of the dead trees renders them almost immediately unmerchantable. Much of this waste can be avoided and the remaining trees benefited by removing 20 to 40 per cent of the volume when the stand is 40 or 50 years old. The smaller, unthrifty trees which are likely to die before the next cutting, as well as the taller ones most liable to windfall, should be taken, leaving a moderately open stand of well-developed, vigorous trees with as uniform height and stocking as possible.

In the rare cases where reproduction of other species is not already present, clear cutting may be counted on to perpetuate the existing type. Paper birch up to 50 or 60 years of age reproduces vigorously by sprouts, and aspen up to 70 years by root suckers. These sprouts and suckers at first grow more rapidly than do seedlings, but are even more intolerant of shade and unable to survive the competition of well-established advance growth of other species. When such competition is absent they readily restock the area, if cutting is done before the ages indicated. Aspen is especially prolific in this respect and often produces thousands of root suckers to the acre. Sprouts and suckers are so much shorter lived than seedlings that stands composed chiefly of them should be cut about 20 years earlier.

Where reproduction of other species is already present, but where the owner for some reason desires to continue the production of paper birch or aspen, the problem is much more difficult. Probably the most effective method of solving it would be to burn the area lightly after clear cutting. This would expose the mineral soil and thus restore conditions similar to those which produced the original stand of birch and aspen. Since aspen roots produce suckers freely after a light fire, a liberal representation of these can be expected in addition to reproduction by seed. It is, however, so difficult and expensive to get a burn of just the right intensity without endangering adjacent stands that the method can not be recommended.

The crowns of paper birch and aspen are so light and their utilization is ordinarily so close that only a comparatively small amount of slash results from clear cutting, and this decays rapidly. No special treatment of it is therefore necessary.

YIELDS

Table 13 gives yields of paper birch in merchantable material according to measurements on 46 representative areas (*14*) in Maine. All of the plots measured contained at least 40 per cent paper birch and had a density of over 50 per cent. Where other species were present the figures were reduced to correspond to a pure birch stand. Cubic feet were converted to stacked cords by dividing by 96, and it was assumed that 75 per cent of the total stand consisted of merchantable material.

TABLE 13.—*Merchantable volume of paper birch of average density, Maine; basis, 46 plots*

Age (years)	Volume on good sites	Volume on poor sites	Age (years)	Volume on good sites	Volume on poor sites
	Cords	*Cords*		*Cords*	*Cords*
30	13.3	7.9	60	30.8	22.0
40	19.6	12.4	70	34.8	25.8
50	26.1	17.3			

The yields given represent approximately what may be expected under natural conditions from pure paper birch stands of average density. Mean annual growth at different ages is shown in Figure 15. Aspen stands of the same age show considerably larger average diameters and somewhat higher yields. With both species yields could be increased by the thinning of over-dense stands wherever these are near enough a market to permit utilization of the material removed.

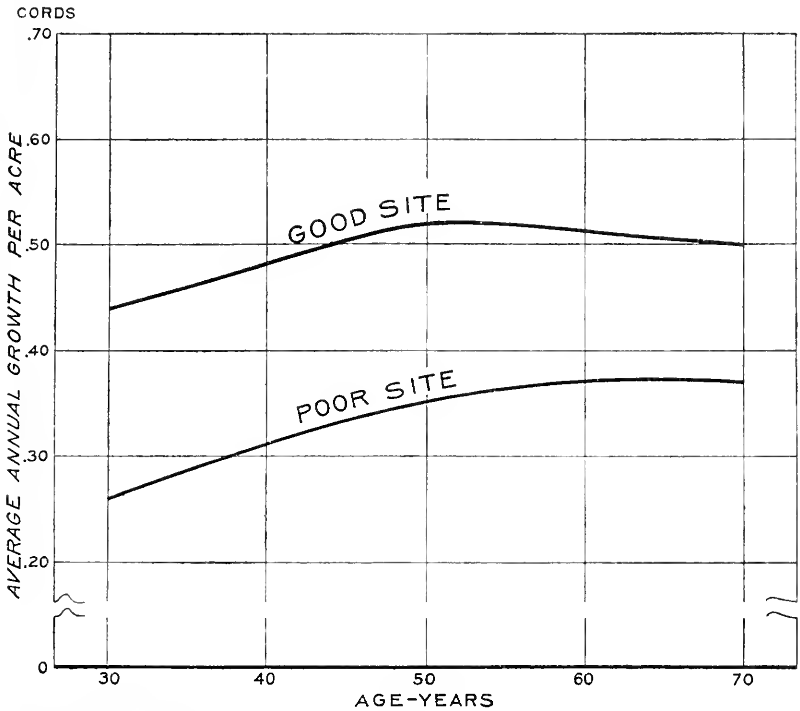

FIGURE 15.—Mean annual growth of pure paper birch in stands of average density

WHITE PINE REGION

The white pine region is characterized by the abundance of northern white pine, sometimes pure and sometimes in mixture with eastern hemlock and a wide variety of hardwoods. The composition of the present stands is strikingly different from that of the original forest, which consisted of a many-aged mixture of white pine and hemlock, with red oak, chestnut, white ash, and other hardwoods. White pine was less abundant than the hardwoods, but was prominent because of the occasional tall trees which towered above the rest of the stand. It has attained its present dominance by its ability to take possession of abandoned farm lands, which cover a large area in this region. This ability is shared with other less-valuable species such as gray birch, aspen, and red maple. These are much more abundant than formerly, and have frequently excluded white pine from areas which would otherwise be occupied by it. The principal forest types are white pine, pine-hardwoods, transition-hardwoods, and gray birch.

The region occupies chiefly the lower elevations in the more thickly settled parts of southwestern Maine, southern New Hampshire, southeastern Vermont, eastern and central Massachusetts, the Champlain Valley in Vermont and New York, and part of the Hudson

River Valley. It is typically a farm-wood-lot region with well developed transportation facilities and good markets.

WHITE PINE TYPES

The white pine type and the pine-hardwoods type are of outstanding importance in the white pine region. A survey by the Harvard Forest of seven representative towns in northern Massachusetts showed that the former constituted 36 per cent and the latter 14 per cent of the forest area of 108,000 acres (*1*). The commercial importance of both types is increased by their usual occurrence within easy reach of good markets.

Northern white pine comprises from 80 to 100 per cent of the white pine type, with varying amounts of pitch pine, Norway pine, eastern hemlock, oak, maple, birch, ash, and occasionally other species. This same group of trees is characteristic of the pine-hardwoods type, in which, however, there is always less pine and much more hardwood. Present stands, unlike those of the original forest, are chiefly even aged. Both types occur on a wide variety of soils and sites.

The pine-hardwoods type formerly covered a much larger area than at present, and in fact made up the bulk of the virgin forest throughout most of the white pine region. The stands were typically uneven aged, usually with scattered white pines under which grew a widely varying mixture of hardwoods and hemlock of all sizes. This mixed forest tended toward one of pine-hardwoods on the deeper, moister soils and toward one of pure pine on the lighter, drier sands.

As the agricultural and industrial development of the region advanced, the forest was cut more and more heavily for its timber, and large areas were cleared for farms. Since the Civil War, the process has been reversed. Farming has waned, the rural population has decreased, and enormous areas of once-cultivated lands have been abandoned, reverting for the most part to forest. Petersham, Mass., for example, which at one time had 60 per cent of its total land area in farms or pasture, now has 68 per cent in forest (*1*, *13*, *17*).

White pine and gray birch are the most aggressive species that restock these abandoned fields. The Harvard Forest survey showed that on the better soils 64 per cent and on the lighter soils 61 per cent of the old fields reverted to white pine, whereas on both sites 16 per cent reverted to gray birch. The white pine type is therefore common on abandoned farm lands, to which it is in fact almost wholly confined except on the lightest soils and occasionally on burned areas. Because of their origin, the white pine stands are even aged and are especially abundant in the more settled portions of the region, where they occur chiefly in the form of farm wood lots.

The ability of the white pine type to act as a pioneer in reclaiming cleared lands has very greatly extended the area occupied. There is every indication, however, that without some help these stands will seldom be able to hold their own. On the medium-to-better soils, there is a marked tendency for hardwoods to come in under the pine, and thus in the next generation to restore the original pine-hardwoods type, or even to establish a pure-hardwoods type. Thus in the seven Massachusetts towns previously mentioned heavy cutting in the white pine type was followed by greatly increased representation of hardwoods on 75 per cent of the better soils and on 46 per cent of the lighter soils.

Under natural conditions, and except on soils too sandy for hardwoods, the white pine type, in spite of its present abundance, is distinctly temporary, marking the transition from cleared land to a stand more or less closely resembling the original forest. Even in the pine-hardwoods type, there is a tendency on the better soils toward increased quantities of hardwoods. The extent to which white pine is retained in both types, therefore, depends largely on the way in which the types are handled.

NATURAL REPRODUCTION

The abundance of white pine on old fields is due largely to the fact that its lighter seeds are blown to greater distances than those of any of the hardwoods except gray birch and aspen. Heavy crops of pine seed are usually borne at intervals of three to five years, and in the mineral or grass-covered soil the seeds find satisfactory conditions for germination and the seedlings for growth. Competition from such hardwoods as do start at the same time is likely to be reduced by the continuation of grazing on the otherwise abandoned fields.

In well-stocked stands of white pine, conditions become more favorable for the hardwoods. An ample seed supply of the lighter-seeded species is furnished by the occasional trees which are nearly always present even in pure stands of pine; and with the establishment of a forest cover the heavier-seeded species are introduced by rodents. When the stands begin to open up, as they usually do between 40 and 50 years of age, an advance growth of hardwoods commonly takes possession of the ground. These seedlings are fairly tolerant of shade and on good soils are able to persist until cutting gives them an opportunity for development (*13*).

White pine, on the other hand, is handicapped by its greater intolerance of shade and by the thick layer of pine-needle litter. This litter is a hindrance to all species, but particularly so to pine, since the roots of the slow-growing seedlings usually dry out in it before they are able to reach the mineral soil necessary for their survival.

The vitality and rate of growth of white pine seedlings under different degrees of shade are indicated by the figures in Table 14, taken from 10 sample plots of 1 square rod each in southern New

TABLE 14.—*Survival and rate of growth of northern white pine seedlings under different degrees of shade in southern New Hampshire; basis, 10 plots of 1 square rod each*

Degree of shade	Average per plot, 1905	Living in 1909	Total height growth, 1905–1909
	Number	*Per cent*	*Inches*
Dense crown cover	271	5.5	3.0
Broken crown cover	102	60.8	8.5
Open crown cover	100	94.0	9.5

Hampshire (*20*). These seedlings, which had been badly suppressed and were therefore gaining very slowly, averaged 1.5 feet in height on all of the plots at the time of their establishment in 1905, and conditions were similar in other respects, except as to shade.

Even in the open, the development of white pine in early youth is much slower than that of the hardwoods, which are nearly always abundant on cut-over areas. The difference in growth is shown graphically in Figure 16, which is based on the measurement of trees with ample opportunity for development on good soils in southern New Hampshire and Massachusetts (*13*). "Seedling sprouts" are those from stumps of 0.5 inch in diameter or less. Sprouts from larger stumps have even more rapid growth.

A similar comparison is afforded by the figures in Table 15, based on about 800 trees not retarded by overhead shade on good soil in northern Massachusetts (*16*).

TABLE 15.—*Comparison at different ages of heights of open-grown northern white pine seedlings and hardwood sprouts in northern Massachusetts; basis, 800 trees*

Age (years)	White pine seedlings	Red oak, white ash, chestnut, and sugar maple sprouts	Red maple, gray birch, and aspen sprouts	Age (years)	White pine seedlings	Red oak, white ash, chestnut, and sugar maple sprouts	Red maple, gray birch, and aspen sprouts
	Feet	*Feet*	*Feet*		*Feet*	*Feet*	*Feet*
1	----------	2.2	3.2	4	1.5	8.2	9.0
2	0.4	4.5	5.3	5	3.0	11.0	11.0
3	.8	6.8	7.3	6	4.0	13.5	14.3

Table 15 is also of interest as showing the more rapid growth of the "weed" species as compared with the better hardwoods. After the white pine is thoroughly established, its height growth increases materially, often exceeding 3 feet a year. It is, therefore, able to hold its own if it can escape being crowded out while it is obtaining a foothold.

White pine reproduces more freely in the lighter litter of the pine-hardwoods type than in the white pine type, but here the hardwoods are also more abundant and competition from them more intense. With their much more rapid initial growth in height and crown area, the hardwoods are almost certain to predominate in the next crop. White pine stands its best chance for development where it occurs, as it often does, in small groups. Under natural conditions these groups are gradually reduced in size by the encroachment of the hardwoods. One or more trees in the center of the group usually persist, however, to form a part of the final crop, and the crowding to which they have been subjected improves the quality of their product. The development of such a group is indicated in Figure 17 (*13*).

METHODS OF CUTTING

The large yields obtainable from white pine, the fine quality of its wood, its high stumpage value, and its usual occurrence in close proximity to good markets have all combined to arouse interest in its perpetuation and improvement. As a result, the white pine type and the pine-hardwoods type have probably received more study and attention than any others in the Northeast.

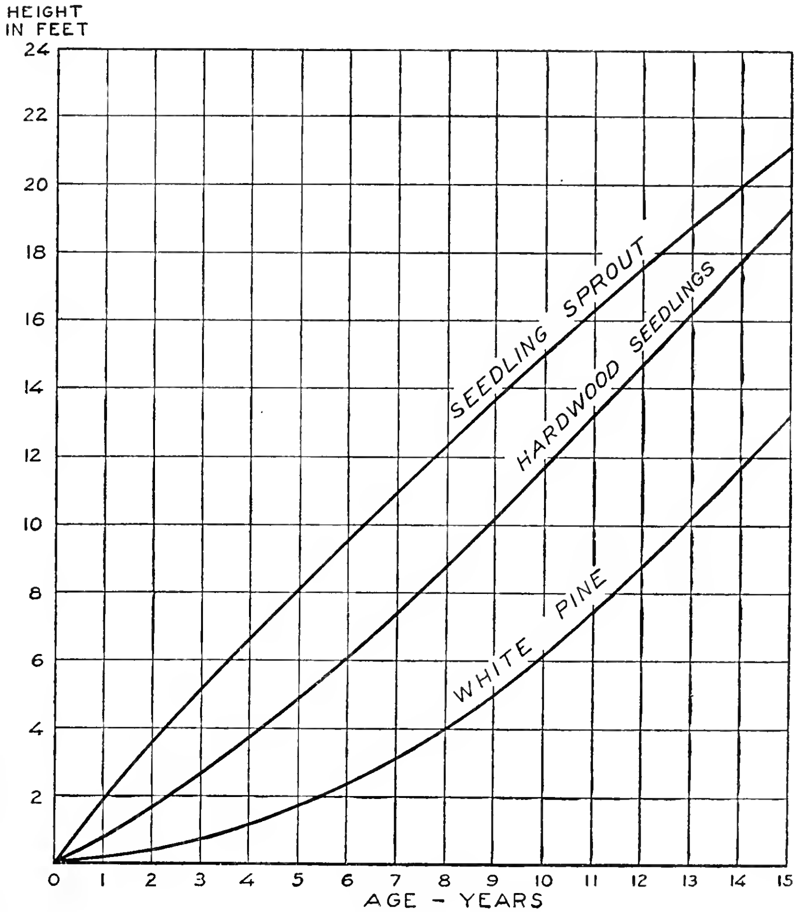

FIGURE 16.—Relative height growth of white pine seedlings, hardwood seedlings, and hardwood seedling sprouts

Until recently the general tendency was to handle every stand with the object of obtaining the greatest possible amount of white pine. It is now being realized that this may be good policy only on the lighter soils that are not well adapted to hardwoods. Elsewhere, the maintenance of a mixed forest similar to that which was originally characteristic of the white pine region, and to which second-growth stands are steadily reverting, is likely to be easier and in the long run more profitable. In addition to its other advantages, a mixed forest improves the quality of the soil, produces higher grade timber, and is usually less liable to injury from insects and disease than is one of pure pine.

Both the white pine type and the pine-hardwoods type can be handled most advantageously by the so-called shelter-wood method,

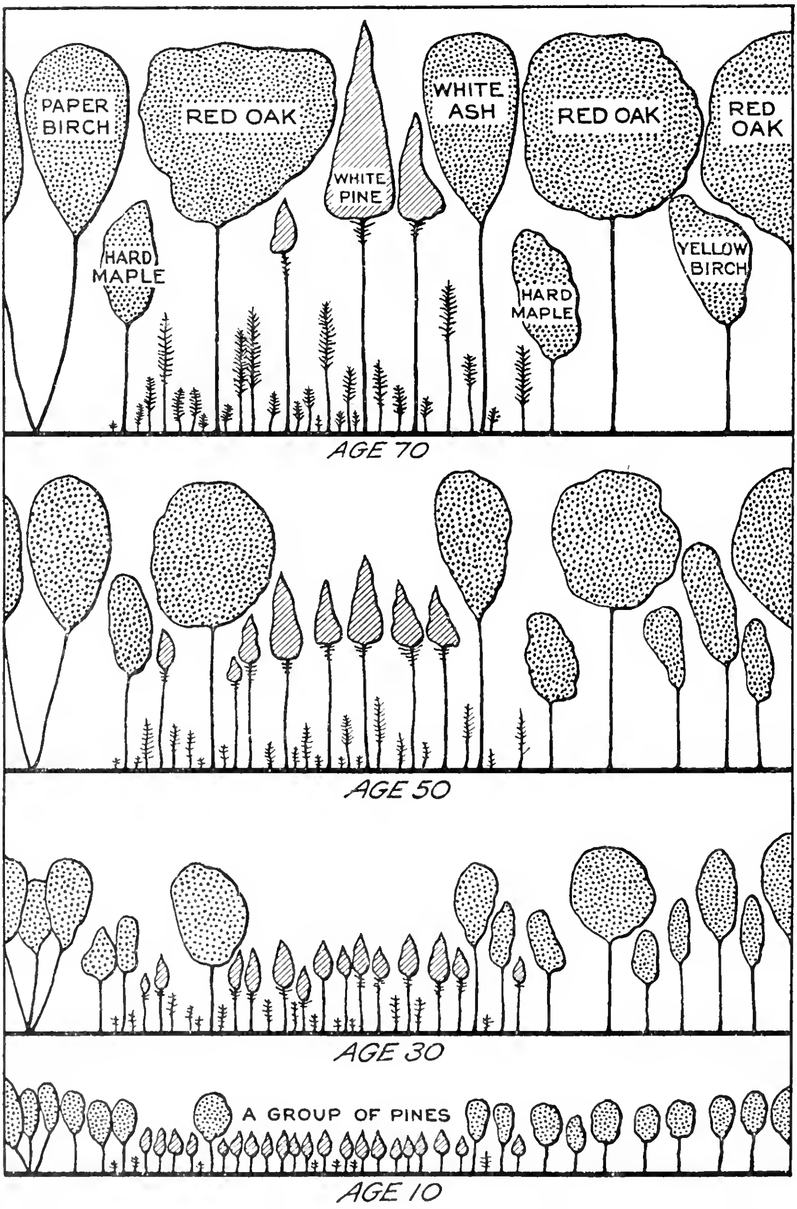

FIGURE 17. The development of white pine grouped among hardwoods. (Courtesy of the Harvard Forest)

by which the mature stand is removed in two (or occasionally three) cuttings several years apart. (Pl. 12.) The first cutting should remove from 40 to 50 per cent of the crown canopy, including both the smaller, less thrifty trees and those with large, spreading crowns which would do much damage if felled after reproduction had become well established. The trees left should be well developed, with medium-sized crowns capable of ample seed production and of increased growth; and in mixed stands white pine should be favored. Logging should, if practicable, be done when there is no snow on the ground, so that the litter and humus may be torn up as much as possible (*13*).

This opening up of the stand will stimulate the development of reproduction already on the ground, will result in the establishment of new reproduction of both pine and better hardwoods, and at the same time will not admit enough light to encourage the more intolerant weed species such as gray birch, aspen, and pin cherry. White pine nearly always comes in abundantly, particularly if the mineral soil is well exposed, and not infrequently runs as high as 25,000 or more seedlings to the acre.

The remainder of the stand should preferably be cut clear when the reproduction resulting from the first cutting is from 4 to 6 years old (*13*). If the final cutting is made earlier, more pine seedlings are likely to be killed by the pales weevil and by the drying out of the surface soil; whereas if the cutting is delayed, the seedlings are likely to become stunted and unable to take prompt advantage of the increased light. Where there is an abundant advance growth of hardwoods, these seedlings are often misshapen and should be cut back to the ground to give the pine a better chance and to insure development of straight, vigorous seedling sprouts. Cleaning can usually be done with a bush scythe at the rate of an acre to an acre and a half per man per day. The cost is more than offset by the increased ease of logging.

On areas where the soil is light and the stand is more or less uneven aged, a heavier first cutting can be made to favor the smaller trees. Here there is less danger that the pine seedlings will be choked out by hardwoods or suppressed by the relatively light overhead cover even if the second cutting is deferred for several years. The smaller trees can, therefore, be left long enough to increase materially in size and diameter. Best results will, of course, be obtained by leaving only thrifty trees that are able to take advantage of the increased growing space. On a tract in New Hampshire where the stand was cut to a fixed diameter limit of 8 inches on the stump, no windfall resulted, and 14 years later some of the trees had increased to a 20-inch stump diameter. Reproduction is often good, particularly if a few of the larger trees are left to serve as seed trees.

In stands of this sort, the increased cost of partial cutting as compared with clear cutting is more than offset by the higher quality of the timber removed. A good example of this is afforded by two practically adjacent lots in southern Maine—one in private ownership, the other owned by Bates College. On the privately owned lot, where clear cutting was practiced at a cost of $10 per thousand board feet for logging from the stump to the cars, 70 per cent of the lumber was of such low grade as to be suitable only for box boards or framing. On the Bates College lot only the mature trees, comprising about 65 per cent of the stand, were removed. The cost of logging was $2 per thousand more than on the clear-cut lot, but fully 80 per cent of the timber went into square-edged lumber of high grade.

Clear cutting may result in satisfactory reproduction of pine in the comparatively rare stands where a satisfactory understory of pine is already present, or when the cutting is done during a good seed year. (Pl. 13.) Since white pine seeds require two years to mature, it is possible to determine the probable production of seed a year in advance, but it is not always possible to arrange logging operations so as to take advantage of this knowledge. When cutting can be arranged to coincide with a good seed crop, it should be done after the seeds have fallen, which is usually in September. If done before, the seeds will for the most part be buried in slash piles, or destroyed completely if the slash is burned. (Pl. 14, B.)

A study by the Harvard Forest (*18*) of 54 cut-over areas representing upwards of 4,000 acres in northern Massachusetts and southern New Hampshire threw the following light on the results of clear cutting. Of the 54 separate areas examined only 14 had a satisfactory reproduction of pine, or as many as 500 thrifty seedlings per acre. All of these 14 lots were cut in seed years, in the autumn or winter following the fall of the seed. Two other lots cut in seed years showed no reproduction, the failure being due to the fact that the previous stands were unusually dense and below the seed-bearing age. The remaining wood lots were cut over in nonseed years; of these only 10 showed any pine reproduction at all, and only 1 out of the 10 anything like a sufficient seeding. There was no evidence of reproduction from seed stored in the leaf litter more than 1 year, and if seedlings failed to start within from 1 to 5 years after the cutting, the development of other vegetation kept them out entirely. In all, about 15 or 20 per cent of the total area of the wood lots examined supported good pine reproduction, and on another 20 per cent pine seedlings were scattering. On the other hand, 60 to 70 per cent of the area cut in both seed years and nonseed years was satisfactorily stocked with valuable hardwoods, such as red oak, white ash, and sugar maple.

Satisfactory reproduction of white pine is, therefore, rarely obtained when clear cutting is done in nonseed years, and even in seed years is less certain than under the shelter-wood method. The chances of success in nonseed years are somewhat increased by leaving four or more seed trees to the acre. These should be 10 inches or more in diameter and should have good-sized, well-developed crowns capable of producing an ample supply of seed of good quality. Small, poorly developed trees, such as have often been left, bear little or no seed.

CLEANINGS AND THINNINGS

Whatever method of cutting is used to start the new stand, subsequent "cleanings" will ordinarily be necessary to maintain the desired proportion of white pine and better hardwoods and to give them ample opportunity for development. The study of the cut-over areas just referred to indicated that however successful the reproduction may be at the start, under natural conditions, 10 years later 10 to 80 per cent of the desirable elements, both pine and hardwood, is liable to be overtopped and suppressed by inferior species and clumps of stump sprouts. (Pl. 14, A.)

In both the white pine type and pine-hardwoods type such undesirable species as red maple, gray birch, and aspen are usually present after cutting, and because of their more rapid height growth interfere seriously with the production of fully stocked, rapidly growing stands of white pine, white ash, red oak, yellow birch, black cherry, sugar maple, basswood, and other valuable hardwoods.

Table 16 gives the reproduction one year after final cutting by the shelter-wood method and five years after clear cutting (*16*, *18*) on two representative areas in the pine and hardwoods type. Although pine and valuable hardwoods were present in sufficient numbers to form an excellent stand, there was little chance of their being able to do so unless afforded some relief from the competition of the 10,040 red maples on the shelter-wood area and from the 2,640 red maple, gray birch, and aspen on the clear-cut area. Both red maple and gray birch reproduce readily on a wide variety of soils, but with a tendency for the maple to predominate on the better and the birch on the poorer sites. The comparatively heavy foliage of the maple increases the danger of suppression, and the slender twigs of the birch do much damage to neighboring pines by whipping off their leaves and buds.

TABLE 16.—*Reproduction in the pine-hardwoods type following logging by the shelter-wood method and clear cutting*

Species	Trees per acre 1 year after shelter-wood cutting		Trees per acre 5 years after clear cutting[1]	
	Number	*Per cent*	*Number*	*Per cent*
White pine	3,350	18.0	990	9.1
White ash	2,400	12.9	2,020	18.7
Black cherry	1,250	6.7	2,960	27.4
Red oak	570	3.1	960	8.9
Other valuable hardwoods	850	4.6	1,250	11.6
Red maple	10,040	54.0	500	4.6
Gray birch	130	.7	990	9.1
Aspen			1,150	10.6
Total	18,590	100.0	10,820	100.0

[1] Includes only the number of clumps of seedling sprouts and stump sprouts.

Experience shows that where the weed species are abundant they should ordinarily be cut back when they are about 3 to 5 years old, and 5 to 8 feet high. White pine reproduction resulting from clear cutting will then be hardly a foot high; that obtained by the shelter-wood method will average about 3 feet. Both seedlings and sprouts should be removed wherever they are interfering with white pine, valuable hardwoods, or hemlock, but they need not be cut where they themselves are clearly becoming suppressed. In some species, particularly aspen, cutting the stem only part way through and then bending the top down to the ground has apparently decreased the vigor of the succeeding sprouts. Hemlock should be favored not because of any expectation that it will form an important part of the final crop, but because of its value in killing off the lower limbs and thereby increasing the quality of the associated pine and hardwoods.

On sites where the reproduction contains a large proportion of valuable hardwoods, some of these will also have to be removed if it is desired to maintain a mixed stand of pine and hardwoods. If so, advantage should be taken of the usual tendency of white pine to occur in groups. If these groups are saved from suppression by cutting back all of the hardwoods within them, they will eventually produce one or more pines of high quality. Between the groups of pine the better hardwoods should be favored by removing the weed species and the less desirable trees of all species.

On good soils a second weeding will usually be necessary in about five years, when the hardwoods will again be overtopping the pine. This is particularly true if the pine seedlings are less than 3 or 4 feet high at the time of the first cleaning, as they usually are after clear cutting. The second cleaning should be of the same general character as the first, but may not need to include quite so many trees. By 10 years of age the pine has normally attained a rate of growth approximately equal to that of the hardwoods. Two cleanings are, therefore, usually sufficient to enable it to hold its own, although three may sometimes be necessary on the best sites, where hardwoods make their most rapid growth.

The cost of cleaning ranges from about $2 to $8 per acre, depending on the number and size of the hardwoods present and on the care with which the cleaning is done. On the Harvard Forest, cleanings undertaken before the hardwoods have passed the small sapling stage have been done at the rate of 1.5 to 2.5 acres per man per day. Areas which have been cleaned twice and which are in condition to produce valuable timber without further expense have ordinarily cost from $7 to $9 per acre *(18)*.

On light sands, where hardwood competition is less intense, cleaning can be deferred until the pines are from 4 to 5 feet high. By this time the hardwoods will be large enough to use for fuel wherever there is a market for small-size material. Cleanings in such stands on the Yale Forest in southwestern New Hampshire have frequently been made not only without incurring any net cost but at a profit of from $0.50 to $1.50 per cord for the material removed. Under such circumstances one cleaning may be enough to assure a good stand of pine, particularly where gray birch is the predominant hardwood; but as a rule a second cleaning will materially increase the rate of growth of the pine. Badly suppressed pines usually require a year to adjust themselves after being released, but thereafter develop rapidly.

Cleaning has not yet been practiced long enough to make available exact figures as to its effect on yield. In many cases, however, observations of adjacent and originally similar stands make it clear that the large proportion of white pine which is now certain in the final crop as a result of cleaning would have been greatly decreased or entirely eliminated without such assistance. Equally good results are often obtained with the more valuable hardwoods, their representation in the stand being much greater than it would have been with unrestricted competition of the inferior species. In general, cleaning improves the composition of the stand in much the same

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FIRST STEP IN THE CONVERSION OF THE BIRCH-ASPEN TYPE TO CONIFERS

The paper birches which constitute the bulk of the stand are comparatively short-lived trees and will be gradually replaced by the more tolerant and persistent spruce and balsam fir seedlings. (Grafton County, N. H.)

FIRST STEP IN SHELTER-WOOD CUTTING

A well stocked stand in the white pine type without advance reproduction before (A) and after (B) a shelter-wood cutting has been made to stimulate reproduction. The remainder of the stand will be removed after the reproduction has become well established. (Photographs by courtesy of the Harvard Forest.)

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WHERE ADVANCE REPRODUCTION IS PRESENT, RESULTS OF CLEAR CUTTING IN WHITE PINE ARE GOOD

A, Excellent advance reproduction in a white pine stand ready for cutting in Merrimack County, N. H.; B, the result of clear cutting in a stand in Cheshire County, N. H., where white pine reproduction was already well established, as in A.

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A, A stand of white pine in need of thinning. By taking out the inferior, less thrifty trees in this stand in Belknap County, N. H., the growth of those left can be considerably increased. B, Clear cutting in the white pine type without advance growth. This practice is unlikely to give satisfactory results. Reproduction is impossible under the heavy piles of slash, and these piles are also a serious fire menace. (Cheshire County, N. H.)

way as would planting, and it has the great advantage of being much cheaper. Indeed planting must often be supplanted by cleaning in order to assure the establishment and satisfactory development of the plantation.

A crude form of cleaning may be practiced by allowing stock to graze on cut-over areas. Both cattle and sheep browse on the hardwoods and thus tend to favor the white pine, in spite of some injury to the latter by trampling (*46*). While grazing is thus a cheap and partially effective method of saving considerable pine from suppression, it is also very apt to result in serious damage to the better hardwoods, and is much less satisfactory than cutting.

Early cleanings should be supplemented by later thinnings to prevent overcrowding. The maintenance of a fairly dense stand at all ages is essential in order to make full use of the productive capacity of the soil and to grow timber of high quality; but the number of trees necessary to do this decreases steadily as the stand becomes older. Thus, a pure pine stand which starts with 10,000 trees to the acre may be well stocked with less than 300 trees when it is 60 years old. Under natural conditions this reduction in numbers is brought about by the intense competition which exists in crowded stands, but is usually accompanied by complete loss of the material in the trees which drop out and by decreased growth in those which remain. Better results can be obtained less wastefully if the competition is relieved by judicious thinnings.

To obtain the best results, the first thinning should be made soon after real crowding begins, which on good soils may be as early as 15 years, and in the majority of well-stocked stands by 20 or 25 years of age. A good general rule is to start the work as soon as the material to be removed can be marketed without loss; too long a delay is likely to find white pines with such small crowns as to prevent them from making the increased growth of which they would earlier have been capable.

In thinning white pine and hardwoods both, the object should be to favor the thriftier, better-formed trees. This can be done by removing most of the smaller and intermediate individuals and enough of the larger ones to afford ample growing space for those that are left. Badly suppressed trees, however, need not be removed, since they no longer interfere with the development of the stand but help to promote natural pruning. Hemlock is also valuable for this purpose and should usually be left. Trees which are markedly taller than their neighbors, particularly hardwoods, should be cut to prevent their developing into "wolf" trees, as should also undesirable hardwoods and poorly shaped, unthrifty, and defective individuals of all species.

In less than five years white pine will ordinarily fill up completely a space of 3 to 5 feet between adjacent crowns. Larger openings will occasionally be necessary, but they should be avoided as much as possible because of the probability that they will produce limby trees of relatively poor quality. For naturally narrow-crowned hardwoods such as white ash, more room for expansion should be provided than for broad-crowned species such as red oak. In mixed stands a special effort should be made to give every opportunity for development to groups of white pine and to particularly promising hardwoods.

The results to be obtained from thinnings are indicated by certain experiments (*25*) in southwestern New Hampshire which have been under way since 1905. One plot was left unthinned, and a second was lightly thinned and the third heavily thinned in 1905, 1915, 1920, and 1925. All three plots were in a 35-year-old stand of pure white pine on sandy soil of rather poor quality. The influence of the thinnings on volume and on rate of growth is shown in Table 17.

TABLE 17.—*Influence of thinning on volume per acre and rate of growth during a 20-year interval, 1905–1925*

Character of plot	Volume before thinning	Volume removed	Volume 20 years after thinning	Total yield [1]	Mean annual growth per acre
	Board feet	*Board feet*	*Board feet*	*Board feet*	*Board feet*
Unthinned	14, 256		30, 520	30, 520	813
Lightly thinned	13, 084	10, 056	21, 608	31, 664	929
Heavily thinned	14, 664	15, 294	17, 562	32, 856	910

[1] This is the volume in 1925 after thinning, plus the quantity removed in thinnings.

Although the 1925 volume in the unthinned stand is considerably greater than in either of the others, if the large volume removed in thinnings is taken into account, it is evident that the thinned stands lead both in total production and in rate of growth. Moreover, the present volume is concentrated on a much smaller number of trees of larger size and better quality. On the basis of the reduced capital left after the thinning in 1905, the mean annual growth has been 8.6 per cent in the lightly thinned plot and 7.8 per cent in the heavily thinned plot, as against 5.7 per cent in the unthinned plot.

Thinning experiments at the University of New Hampshire show that at ages between 30 and 50 years it is possible to remove from well-stocked white pine stands an average of 1 cord per acre per year, and at the same time increase the rate of growth of the remaining trees. In certain plots where this has been done for 12 years, there is now 20 per cent more volume than in adjacent unthinned plots with twice the number of trees.

Another example of the possible profit from thinning is offered by a tract under private ownership in southern Maine. Here, 5,540 board feet and 14 cords of wood per acre were removed from a sample plot at a net profit of $78.80 per acre. In addition to this profit the thinned area is now in better condition and will grow more rapidly than the adjacent unthinned forest.

Artificial pruning of white pine offers another means of increasing considerably the value of the final crop. Trees in open-grown stands retain their limbs almost indefinitely and have so many and such large knots as to reduce greatly the value of the lumber produced. Natural pruning gives better results in well-stocked stands, particularly when the pine is mixed with hardwoods or hemlock, but even dead limbs are retained for many years and decrease the amount of clear lumber when cutting is done before 60 or 70 years of age, as is now usually the case.

If all limbs are removed from the lower 16 feet of a tree when it is 3 or 4 inches in diameter, clear lumber will be produced by the butt log from then on. They should be cut off clean and close to the bark, preferably with a short crosscut saw mounted on a long pole. When the work is done in this way the wound heals over quickly and there is little danger of forming pitch streaks or pitch pockets or of starting decay. Unsatisfactory results are usually due to careless pruning with an ax or club, and particularly to the leaving of projecting stubs. Only the best trees which are to form part of the final crop should, of course, be treated.

Experiments by a private owner in central New Hampshire (*6*) covering a period of 20 years indicate that one man with a saw can prune 100 feet of stem, or six 16-foot logs, per hour. At 50 years of age these logs should yield about 1,000 board feet of lumber of high quality. In one instance the lumber sawed by this owner from pruned logs brought $65 a thousand feet, when he was having difficulty in selling box boards from similar unpruned material for $25 a thousand. In general, the skilful pruning of well-selected stands of white pine may increase the value of the final product from $15 to $35 a thousand feet, in addition to 6 per cent compound interest on the investment. On the other hand, the pruning of trees which are poorly formed or over 6 inches in diameter is likely to prove very unprofitable (*12*).

Because of the common occurrence of the white pine type and the pine-hardwoods type in the vicinity of good markets, cleaning, thinning, and pruning are all practicable operations in most stands. Thinning, in fact, can usually be counted on to yield a substantial profit. Improvement of the forest by these means should prove especially profitable and worth while on the farm wood lot, since it can be done to advantage during the winter when scarcity of other work affords ample time for the owner to handle it himself with little or no cash outlay.

SLASH DISPOSAL

With utilization to a 5-inch top diameter, as is now common with white pine, a large amount of slash is left after logging in well-stocked stands. A survey of seven towns in north-central Massachusetts shows that about 40 per cent of the total area of cut-over land in the white pine type is covered by slash (*1*). This is for the most part in piles and windrows which are dense enough to keep out all reproduction, often for as long as 20 years. Some method of reducing the amount of slash is, therefore, essential for the production of well-stocked stands.

Wherever the market for fuel permits, the cheapest and most satisfactory method of slash disposal is to cut up and sell the tops for this purpose. From two-fifths to 1 cord of fuel wood can usually be obtained for every thousand board feet of lumber cut. This method has been used successfully on the Bates Forest, in southern Maine (*37*), and on the Yale Forest, in southwestern New Hampshire. The net profit from the material cut from the tops averages from 25 to 50 cents per cord and occasionally runs as high as 75 cents. Taking out the cordwood so greatly reduces the amount of material that no further disposal is necessary, particularly if the branches which are too small to be utilized are well scattered.

In clear cuttings where the sale of fuel wood is not practicable the slash can either be burned as logging proceeds or thrown into large piles or windrows for subsequent burning. The latter method is cheaper, but there is greater danger that the fire will get out of control. It also destroys both existing reproduction and seed on a much larger part of the area.

In shelter-wood cuttings the slash should preferably be gathered in small piles and burned as the logging proceeds. Burning will thus be confined to the smallest possible area, with minimum injury to the remaining stand at the first cut and to reproduction at the second cut.

Costs of slash piling and burning are influenced by a large number of factors, chief among which are the size and form of the tree crowns. These may vary from 15 to 50 feet in length and correspondingly in width in stands of the same age but of different density and composition. As a rule, the cost varies from about $0.50 to $1.25 for every thousand board feet of timber cut. It averages considerably higher on areas cut by the shelter-wood method than on clear-cut areas, especially when the slash on clear cuttings is burned in windrows (*13*). On the other hand, the clearing up of the area effected by burning in small piles as logging proceeds may materially reduce the cost of logging by the shelter-wood method. Slash disposal is now practiced only on isolated cuttings, and costs may be expected to decrease as its use becomes more general. Elsewhere, experience and a genuine desire to do a good job have been found decidedly effective in this respect.

Where there is a market for fuel, hardwood tops should be cut up and sold in the same way as white pine. Elsewhere, no special effort need be made to dispose of them, since they decay rapidly and are so open that they seldom interfere seriously with the establishment of natural reproduction.

DISEASE AND INSECT CONTROL

The white pine blister rust (*Cronartium ribicola* Fischer) is a fatal disease of 5-needle pines which must be controlled if white pine is to be grown commercially as a crop (*42, 43*). This fungus was introduced from Europe on nursery stock about the beginning of the present century, and is now firmly established in the Northeast. It attacks white pine trees of all ages, but is particularly destructive of young reproduction.

The disease can not spread directly from one pine to another, but must spend a part of its life on the leaves of currants or gooseberries. It can, therefore, be controlled by the eradication of these bushes. Cultivated black currants are particularly dangerous in spreading the disease, and should not be grown in white pine regions. All other currants and all gooseberry bushes, both wild and cultivated, should be uprooted within 900 feet of white pine stands. To prevent sprouting, the entire root, particularly the crown, of each bush must be pulled up; it is not sufficient to cut back the tops. After a period of from 3 to 7 years, depending on conditions, the ground should be reexamined and any regrowth of currant or gooseberry bushes destroyed. The cost of the initial control work will vary from 10 cents to $2 per acre, depending chiefly on the number and size of the bushes, density of undergrowth, and topography. On 6,837,385 acres cleared of such bushes in New England and New York from 1918 to 1928 the cost averaged only 21 cents per acre. The cost of any reeradication work will be much less.

Such measures are absolutely essential if the production of white pine is to continue. The cultivated black currant is so dangerous that its growing should be prohibited by law and the destruction of all existing bushes required. The State forester, or other appropriate official, should be authorized to establish quarantines against planting within the State other species of currants and gooseberries, and to require the eradication of existing bushes wherever their presence endangers either present or prospective stands of white pine. Legislation along these lines is already in effect in most of the Northeastern States. Timberland owners and others should, of course, take steps to eradicate currant and gooseberry bushes from their lands, either on their own initiative or in cooperation with the State authorities.

There are also two insects which must be taken into consideration in the growing of white pine. One of these, the pales weevil (*Hylobius pales*), or snout beetle, is usually abundant on recently cut-over areas, to which it is attracted in large numbers by the odor of white pine stumps, slash, logs, or lumber (*33*). The adult beetles feed voraciously on the bark of young trees, which they kill in a few days. Two and three year old seedlings are preferred and are more easily girdled than those of larger size. Serious damage is seldom done even to trees over 3 feet in height.

The pales weevil migrates freely and is attracted from long distances to freshly cut areas. Here it does most of its damage during the first two years after cutting. Two illustrations of this fact and also of the extent of the damage may be cited from the Harvard Forest (*7*). Three years after a broken stand of limby, pasture-grown white pine had been removed from over a veritable carpet of pine reproduction from 2 to 6 inches high, with very few hardwoods present, not more than 10 per acre of these thousands of young pines were still alive. In another case a plantation of 3-year-old white pine transplants were established in May, 1914, on an area from which a heavy stand of white pine had been cut clear the previous winter. By the fall of 1915, 71 per cent of the planted trees were dead or dying as a result of injury by the pales weevil. (Fig. 18.)

Control of the weevil is difficult. Burning of white pine slash removes a large amount of the material which helps to attract it to cut-over areas; and if the burning is done over pine stumps it will lessen their attractiveness as breeding places. Logs and lumber should also be removed promptly from areas where reproduction is desired. These measures will not prevent an infestation, but will mitigate it.

Where the weevil is a serious menace, the only other safeguard is to obtain natural reproduction in such abundance that a loss of from 50 to 75 per cent will still leave enough seedlings to form the basis for a satisfactory crop. This can usually be attained in successful cuttings by the shelter-wood method, and with the additional advantage that by the time of the second cut the seedlings are getting beyond the stage where they are most susceptible to serious injury. Where clear cutting results in immediate reproduction, as in a good seed year, the bulk of the damage is limited to the second year after cutting, since 1-year-old seedlings are seldom attacked.

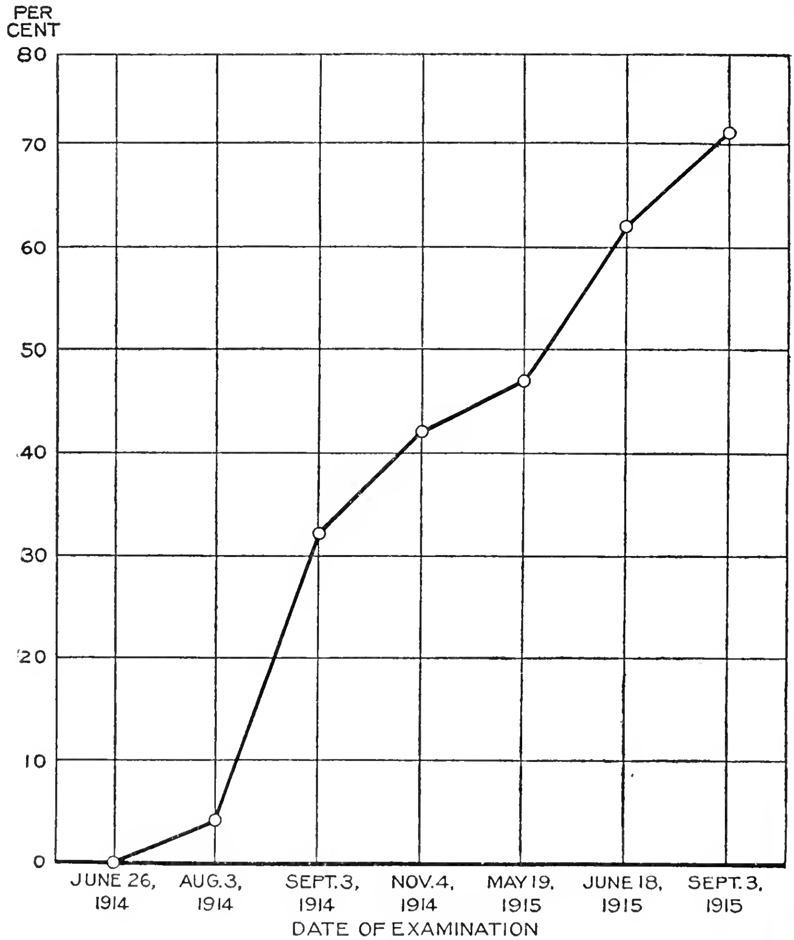


FIGURE 18.—Progress of injury by the pales weevil in a white plantation during the first two years after its establishment

Pine plantations can not safely be set out on cut-over pine areas until the third year after cutting, by which time hardwoods are likely to have obtained a sufficient start to necessitate subsequent cleanings. This applies also to plantations of other conifers, nearly all of which, though less susceptible than white pine, are subject to more or less serious injury, particularly if white pine is absent. For example, in plantations of Norway pine and Norway spruce, 48 per cent and 25 per cent of the trees were killed by the pales weevil during the first year after planting.

The white pine weevil (*Pissodes strobi*) does its damage by deforming rather than by killing the trees (*22*). The destruction of the terminal shoot by the larvae of the insect causes the first group of laterals below the injury to turn up and strive for supremacy. This results in decreased height growth and in a forked or crooked stem. Badly weeviled trees may be practically worthless for lumber, as, for example, in the so-called cabbage or pasture pines, the much-forked trunks of which are due to repeated killing of the leader.

Injury is most common when the trees are between 5 and 20 feet tall (*34*), but may occur at any height. In young stands, and particularly in plantations, as many as 90 per cent of the trees may be affected. The greatest damage is done in stands of pure white pine, where the percentage of weevil injury is much higher than in stands with a considerable mixture of hardwoods. Open-grown stands also suffer severely, since they lack that crowding from the side that is necessary to enable the trees to straighten up and reestablish a single leader. Stands which are dense enough to have 260 or more trees per acre at 50 years of age on average sites, even though weeviled in youth, ordinarily produce material of reasonably good quality.

Weevil damage can be lessened by cutting off the infested leaders in late June or early July before the adults have emerged. These leaders should either be burned or better still placed in an ash can covered with 14-mesh wire screening. The latter will retain the adult weevils but will permit the escape of such parasites of the weevil as may be present. This method of control is too expensive to be carried out on any large scale with natural reproduction. It can, however, be used to advantage with valuable white pine plantations. Cutting of the infested leaders should be begun as soon as the presence of the insect is detected and should be continued each year as long as the leaders can be readily reached.

Other methods of direct control, such as spraying the trees with some repellant, banding them with tanglefoot, and jarring the adult weevils in early spring into a net held at the base of the leader, all appear to be less effective and are also too costly for general use. Parasites help much in keeping the weevil in check, but probably little can be done at present to increase their abundance.

The most effective means of controlling the white pine weevil probably lies in the production of well-stocked, mixed stands. This emphasizes the desirability of letting pure stands of white pine revert to the pine-hardwoods type wherever soil conditions are favorable for the hardwoods. The partial overhead shade afforded by the hardwoods during the first 8 or 10 years in the life of the pine, and the side shade afforded thereafter, will do much to decrease weevil injury. Moreover, in dense stands, such trees as are attacked will have a good opportunity to replace the lost leader and to develop fairly straight stems.

YIELDS

White pine probably produces a larger volume per acre, age for age, than any other species in the Northeast. Measurements of 196 typical fully stocked second-growth stands in New Hampshire are given in Table 18 (*20*).

TABLE 18.—*Volume per acre of fully stocked second-growth stands of northern white pine, New Hampshire; basis, 196 plots*

Age (years)	Volume on— Good sites	Volume on— Average sites	Volume on— Poor sites	Age (years)	Volume on— Good sites	Volume on— Average sites	Volume on— Poor sites
	Board feet	*Board feet*	*Board feet*		*Board feet*	*Board feet*	*Board feet*
30	13, 900	9, 600	5, 300	70	69, 900	56, 100	42, 300
40	32, 800	23, 500	14, 200	80	77, 850	64, 000	50, 100
50	49, 100	36, 600	24, 100	90	84, 800	70, 900	57, 000
60	60, 200	46, 900	33, 600	100	91, 200	77, 000	62, 800

The board-foot volumes show the actual mill tally of all trees 5 inches or more in diameter at breastheight. Sixty per cent of the lumber sawed was round-edged and 40 per cent squared; 70 per cent

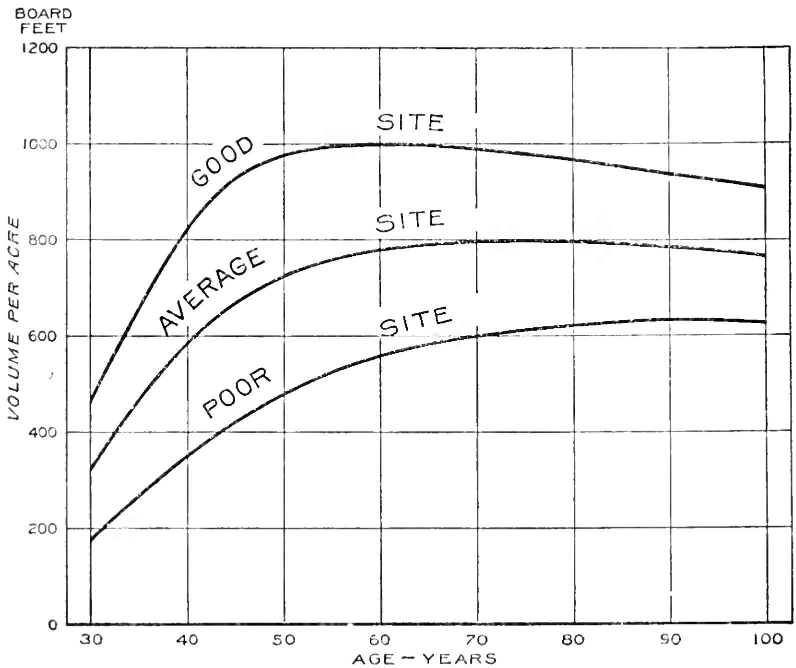


FIGURE 19.—Mean annual growth of fully stocked, even-aged stands of white pine

went into 1-inch boards and 30 per cent into 2⅛-inch plank. The values run somewhat higher than those determined by log scale. Board feet can be converted into cords, which is the unit of measurement often used when pine is cut for pail stock and similar products, on the assumption that there are approximately two cords to every thousand board feet.

The mean annual growth of white pine at different ages is shown in Figure 19. These figures are for unmanaged stands and could undoubtedly be increased by thinnings, which would also produce intermediate yields.

Yield tables have never been prepared on the basis of actual field measurements for the wide variety of mixtures found in the pine-hardwoods type. Theoretical yields have, however, been worked up and are given in Figure 20 (*13*). The average yields for northern

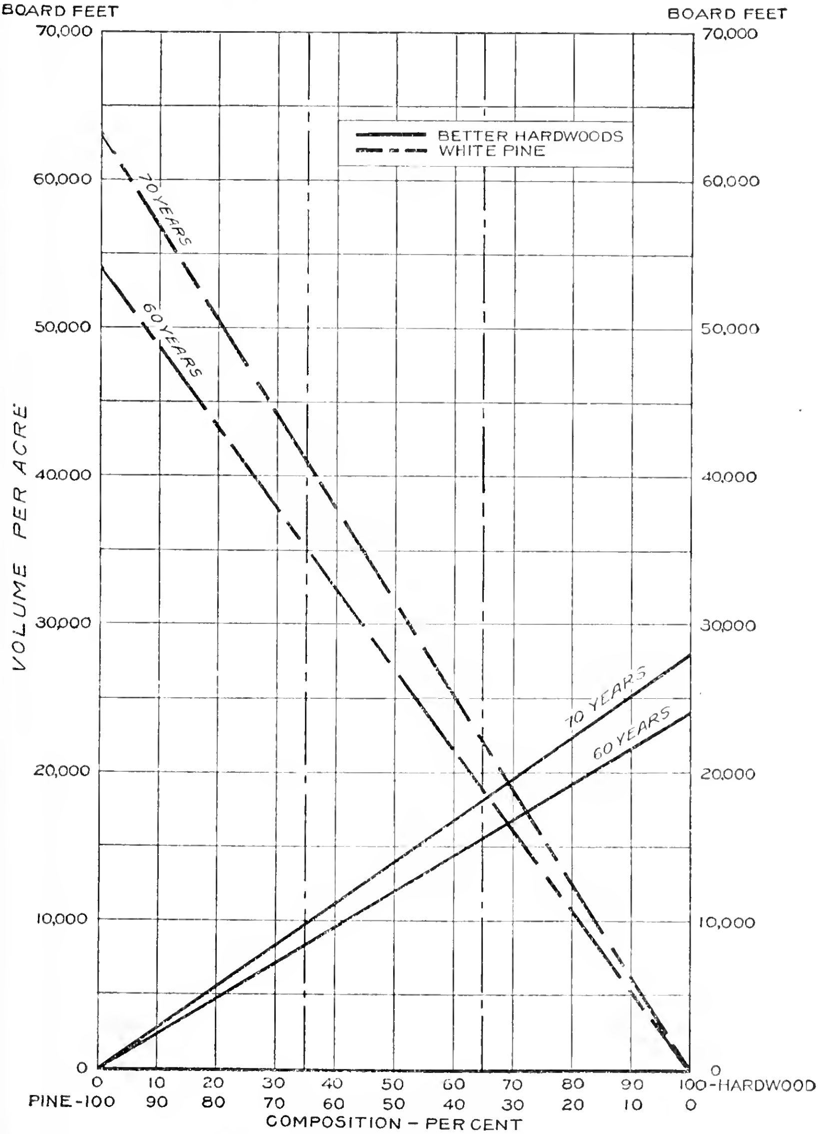


FIGURE 20.—Yield per acre for different combinations of white pine and better hardwoods on the basis of the total area occupied by each. The vertical dash-dot lines indicate the range in composition within which all advantages of the mixtures obtain. (Reproduced by permission from Bulletin No. 8 of the Harvard Forest)

white pine on good and average sites are those indicated in Table 18. Yields for the better hardwoods are taken from average yields of red oak and white ash on good sites as calculated from the study of individual trees and stands. Since all hardwoods tend to approach either oak or ash in form, and since differences in composition in even-aged mixed hardwood stands appear to cause little variation in yield, it is assumed that these figures will hold for hardwoods in general. They are applicable, however, only to natural stands growing under the most favorable conditions, and probably give a conservative estimate as to what can be expected under management.

From Figure 20 the yield of fully stocked stands of northern white pine and hardwoods in any possible mixture can be readily determined when the percentage of area occupied by each is known. For example, if a given stand at 70 years of age contains 60 per cent pine and 40 per cent hardwoods by area the yield of the former will be 37,800, and of the latter 11,000, or a total of 48,800 board feet. The higher yield of the pine is striking. The chief advantages of mixed stands are believed to be obtained when either group occupies at least 35 per cent of the area.

TRANSITION-HARDWOODS TYPE

The transition-hardwoods type is intermediate in composition between the typical birch, beech, and maple forest of the spruce and northern-hardwoods region and the typical oak forest of the oak region. These and other hardwoods are present in a wide variety of mixture, together with occasional eastern hemlock, northern white pine, Norway pine, and red spruce. Measurements of 40 sample plots showing average composition on sites of good and medium quality in northern Massachusetts are given in Table 19 (*40*).

TABLE 19.—*Composition of average stands in the transition-hardwoods type in northern Massachusetts; basis, 40 plots*

Species	Good sites	Average sites	Species	Good sites	Average sites
	Per cent	*Per cent*		*Per cent*	*Per cent*
Red oak	27	20	Sugar maple	3	6
White ash	15	14	Paper birch	2	8
Red maple	15	12	Beech	2	7
Basswood	9	3	Miscellaneous	6	7
Yellow birch	8	10			
Aspen	7	8	Total	100	100
Chestnut	6	5			

The type occurs chiefly on the better sites, such as moderate slopes, benches, and valley bottoms, with fairly deep, fresh-to-moist soils. Perhaps 90 per cent of the stands are on cut-over land, where they frequently follow one of the pine types. These second-growth stands are usually even aged, with a mixture of seedlings and sprouts. (Pl. 15.)

With its many valuable species and common occurrence in the neighborhood of good markets, the transition-hardwoods type is of much importance both commercially and geographically. In the survey of northern Massachusetts towns already referred to it was found to occupy 26 per cent of the total forest area (*1*). It probably formed a still larger part of the original forest, and is tending to increase in area as white pine is replaced by hardwoods.

METHODS OF CUTTING

Satisfactory natural reproduction in the transition-hardwoods type can ordinarily be obtained either by clear, shelter-wood, or selection cutting. Most of the characteristic species are fairly tolerant of shade in early youth, with the result that an advance growth of seedlings is usually present under mature stands. Clear cutting gives this an opportunity for development and at the same time produces large numbers of sprouts from the stumps of the cut trees.

Shelter-wood cutting is decidedly preferable wherever advance growth is scarce or lacking, since on such areas the new crop, even if satisfactory in numbers, will consist almost wholly of sprouts. As in the pine types, the first cut should take about 40 to 50 per cent of the crown canopy, the remainder being removed as soon as seedling reproduction has become well established. Shelter-wood cutting also has the advantage, where such reproduction is already present, of stimulating its growth and thereby enabling it by the time of the final cutting to reach a sufficient height to compete on more even terms with the stump sprouts.

Selection cutting, or the removal year after year of only the larger trees, gives an opportunity for new growth to start in the openings thus made and can be used to advantage in uneven-aged stands. It is particularly profitable for the small owner who wishes to maintain some merchantable material on his land at all times.

Cleanings of young stands are important, and are usually necessary within three to five years after the complete removal of the mature timber. They should aim to favor the best species, notably red oak and white ash. Where these are abundant, and are freed from competition of less desirable species, they may make up as much as 80 per cent of the new crop. Cleanings should also favor seedlings and thrifty, well-formed individuals. In general, they are similar to those in pine and hardwood stands, except for the fact that pine does not have to be taken into consideration. Except where especially troublesome species, such as red maple, are present in large number, one cleaning should ordinarily be sufficient.

Thinnings are advisable as soon as overcrowding begins, say from 20 years on, wherever there is a market for the material removed. Straight, dominant trees of valuable species should be favored, but not those which are so tall as to be likely to develop into "wolf" trees. Frequent light thinnings, at intervals of from 5 to 10 years, are better than infrequent heavy ones.

The slash left after logging decays so rapidly and interferes so little with reproduction that no special disposal is necessary. No stock should be allowed to graze on cut-over lands, since both cattle and sheep are likely to cause serious injury to all species of hardwoods.

YIELDS

The theoretical yield of red oak and white ash at 60 and 70 years of age has already been indicated in Figure 20. Actual measurements (*40*) of 40 sample plots in fully stocked, even-aged stands in which the better hardwoods (chiefly red oak, white ash, sugar maple, and yellow birch) were present in a wide variety of mixtures established cordwood and lumber yields as given in Table 20.

TABLE 20.—*Yield per acre in fully stocked, even-aged stands in the transition-hardwoods type; basis, 40 plots*

Age (years)	Volume per acre on—					
	Good sites			Average sites		
	Cordwood [1]	Saw logs plus cordwood [2]		Cordwood [1]	Saw logs plus cordwood [2]	
	Cords	*Board feet*	*Cords*	*Cords*	*Board feet*	*Cords*
30	29.8			20.4		
40	39.6	4,720	9.2	29.5	1,920	9.1
50	48.0	10,310	8.3	36.0	4,780	12.3
60	55.5	15,620	5.6	41.1	8,660	10.2
70	62.8	19,830	5.3	45.6	12,710	7.1
80	69.5	23,400	5.3	49.8	15,380	6.1

[1] Includes all trees 2 inches and over in diameter.
[2] Includes all trees 7 inches and over in diameter.

Cord volumes were determined with a volume table for red maple, which was found by actual test to be equally applicable to other hardwoods of the same diameter and height. The solid contents of a stacked cord varied from about 67 cubic feet with the smaller trees to about 90 cubic feet with the larger.

Board-foot volumes were computed by the international rule, which gives slightly lower values than those found by mill-scale studies in the same locality. Hardwoods are usually sawed through

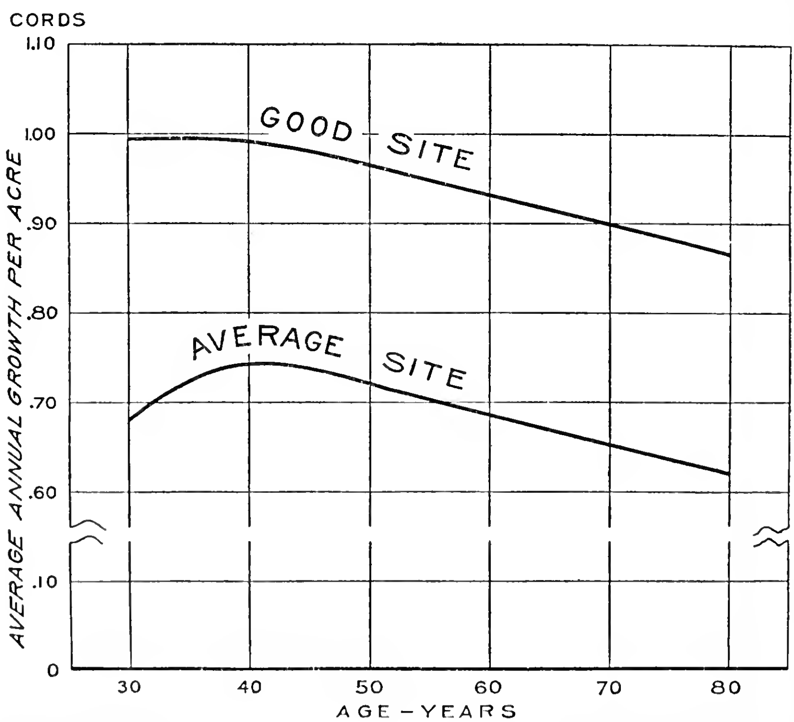


FIGURE 21.—Mean annual growth in cords of fully stocked, even-aged stands of better hardwoods for all trees 2 inches and over in diameter at breastheight

and through into round-edged lumber. Any tree is considered merchantable which will give an 8-foot log out of which a board with a minimum width of 5 inches can be sawed. The "additional cords" were determined by finding the total contents of the trees in cords and subtracting from this figure the cord equivalent of the board-foot contents, on the assumption that there were 6 board feet to the

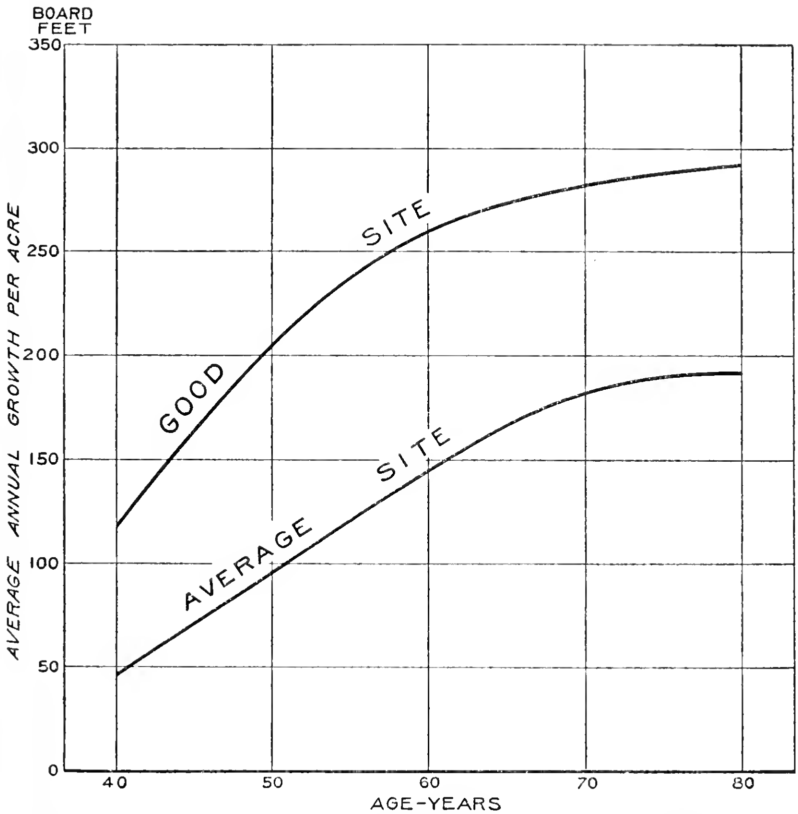


FIGURE 22.—Mean annual growth in board feet of fully stocked, even-aged stands of better hardwoods for all trees 7 inches and over in diameter at breastheight

cubic foot and 65 cubic feet to the cord. Material in trees from 2 to 5 inches in diameter, which can also be utilized where there is a good market for fuel, varies from 18.3 cords at 40 years of age to 3.9 cords at 80 years on good sites, with slightly smaller yields on average sites.

Average annual growth per acre is shown in Figures 21 and 22. The comparatively uniform growth of nearly 1 cord per acre per year on good sites and of nearly 0.7 of a cord on average sites between 30 and 80 years of age is very striking. Better results could undoubtedly be obtained with thinnings.

GRAY BIRCH TYPE

The gray birch type occurs extensively throughout the white pine region and is also common in the sprout-hardwoods region. Gray birch is the characteristic and predominant species, usually in mixture with more or less red maple and aspen. Other hardwoods and occasionally pine occur scatteringly in wide variety. The average distribution of species on eight sample plots in northern Massachusetts is given in Table 21 (*40*).

TABLE 21.—*Distribution of species in the gray birch type of the Northeast; average of eight plots in northern Massachusetts*

Species	Distribution	Species	Distribution
	Per cent		*Per cent*
Gray birch	38	Sugar maple	2
Red maple	24	Red oak	2
Aspen	15	Miscellaneous	12
Yellow birch	4		
Paper birch	3	Total	100

The type is found on nearly all sites from dry to wet, and from sterile to fertile. Gray birch and aspen are so intolerant of shade that they seldom come in under the cover of existing stands. Their light seeds and common occurrence, however, enable them to reproduce abundantly in the form of even-aged stands on areas that have been cleared by cultivation, fire, or logging. The type is particularly characteristic of old fields, but also frequently follows cutting in the white pine type. The Harvard Forest's survey of northern Massachusetts towns showed this to be true in 25 per cent of the stands examined.

This same survey showed that 17 per cent of the total forest area in that part of the region was occupied by the gray birch type. Locally it is often still more abundant. In spite of its large area, however, it is of comparatively little commercial importance because of the small size and inferior quality of the short-lived gray birch and aspen. If fire is kept out, it is also a distinctly temporary type, since the light foliage and comparatively open crowns of these species permit white pine and the more valuable hardwoods to seed in and eventually to replace them.

The gray birch type is, therefore, constantly coming in on certain areas and being crowded out on others. It has undoubtedly increased in abundance during the last few decades and is probably still gaining ground. This is due in large part to the fact that gray birch, aspen, and red maple have been cut far less heavily than their more valuable associates, and have thus had every opportunity to spread. Their more rapid early height growth also gives them a distinct advantage over their competitors in uncleaned stands.

METHODS OF CUTTING

The chief object of cutting in the gray birch type is not to perpetuate it but to hasten its reversion to a forest of more valuable species. This can be done, wherever gray birch, red maple, and aspen can be marketed for fuel, by clear cutting as soon as the stand reaches merchantable size. Complete removal of these inferior species is ordinarily sufficient to enable the advance reproduction of white pine and of the more valuable hardwoods, such as red oak, white ash, and yellow birch, to take possession of the area. Subsequent cleanings may, however, be needed if the advance growth has not reached a sufficient height to hold its own with the vigorous sprouts which will spring from the stumps of the cut trees.

In areas where the gray birch type is not being replaced naturally by some other type, planting, particularly of white or Norway pine, may be profitable. This can best be done under the shade of the existing stand, which should be removed from three to eight years later, after the pine has become thoroughly established. If the pine is allowed to reach a height of about 4 feet before the stand is removed, subsequent cleaning will seldom be necessary.

Slash resulting from the cutting of gray birch and its associates is ordinarily so light and decays so readily that no disposal of it is necessary.

YIELDS

Measurements of eight sample plots in northern Masachusetts containing fully stocked, even-aged stands of inferior hardwoods (*40*) give the yields presented in Table 22.

TABLE 22.—*Yield per acre in fully stocked, even-aged stands of the inferior hardwoods of the gray-birch type in northern Massachusetts; basis, eight plots.*

Age	Volume per acre on good site
	Cords
20 years	18.1
25 years	20.5
30 years	20.6

Soil conditions were slightly better than average for this type. All trees 2 inches or over in diameter at breastheight are included. Cord volume was determined in the same way as for the better hardwoods. (Table 18.) Since gray birch deteriorates rapidly after it is 30 years old, there may be an actual decrease in yield after that age, depending on the amount of gray birch in the stand.

The mean annual growth drops from nine-tenths of a cord per acre per year at 20 years of age to two-thirds of a cord at 30 years.

OAK REGION

The oak region is characterized by a varying mixture of oaks, hickories, maples, and birches, with some yellow poplar and other hardwoods on the better sites. Chestnut was formerly abundant, but nearly all trees of merchantable size have now been killed by the blight. Repeated cuttings and fires have been responsible for the replacement of hemlock, which was also much more common in the original forest, by the more aggressive hardwoods. White pine is relatively scarce in spite of the large area of abandoned farm lands.

The predominant types are oak, gray birch, and hardwood-swamp. In addition, the white pine type and the pine-hardwoods type are found in the oak region, but they occupy a much smaller area than in the white pine region. The mixed-hardwoods type of the Allegheny hardwoods, pine, and hemlock region also occurs here on the better sites.

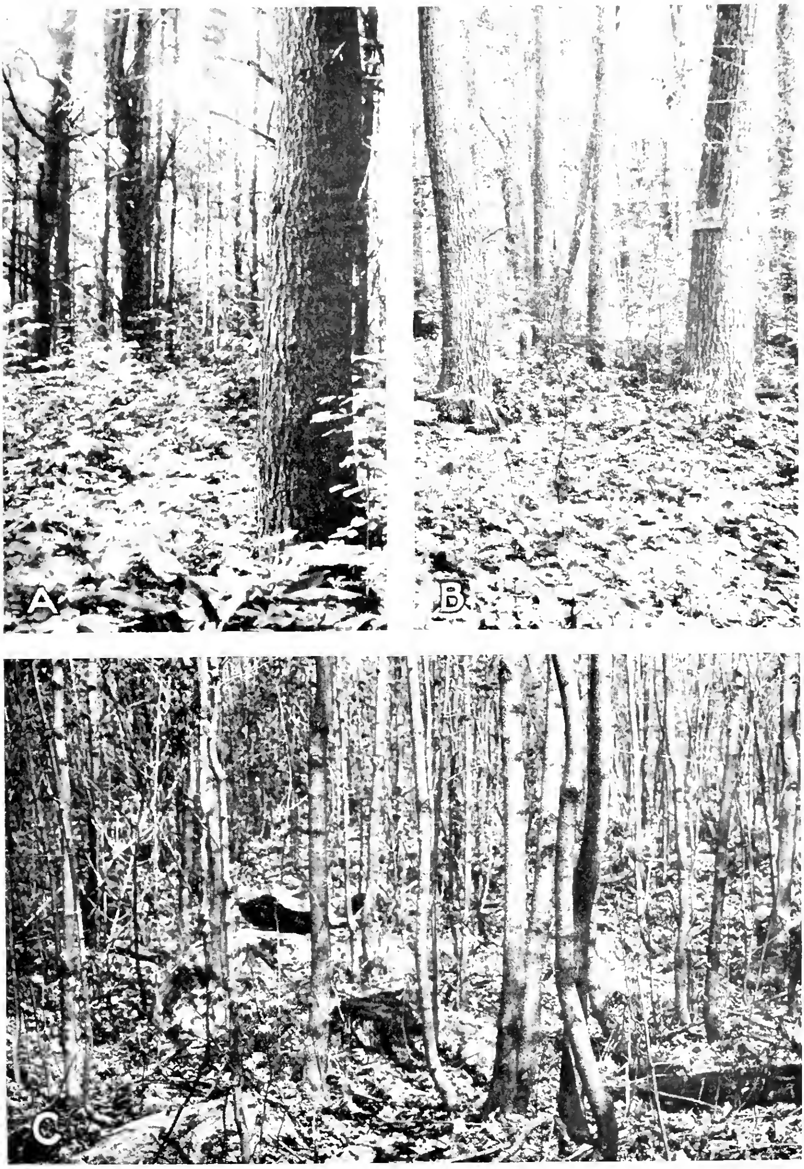
The region occupies most of Rhode Island, Connecticut, northern Long Island, the Hudson River Valley, the valleys of northern and western New Jersey, eastern and southwestern Pennsylvania, exclusive of the Poconos, and a belt along the south shore of Lake Ontario. The elevations are mostly low and the topography flat or slightly rolling. Like the white-pine region, the oak region is thickly settled, has good markets and good transportation facilities, and maintains its forests largely in the form of farm wood lots.

OAK TYPE

The oak type is both geographically and commercially of outstanding importance throughout the oak region. (Pl. 16, A.) Red, white, chestnut, black, and scarlet oak usually constitute from 50 to 90 per cent of the stand. Numerous other hardwoods, such as red and sugar maple, shagbark, pignut, and mockernut hickory, sweet birch, white ash, black cherry, beech, and yellow poplar, are present in widely varying numbers. Minor species, often prominent in young but seldom in mature stands, include dogwood, hophornbeam, blue beech, sassafras, gray birch, and aspen. Chestnut, formerly so abundant as to receive recognition as a distinct type, has now been practically exterminated in merchantable size by the blight (*Endothia parasitica*) and is being replaced chiefly by oak (*28*, *29*). Hemlock was in all probability common in the original forest in the northern part of the region, but has been greatly reduced in numbers by repeated clear-cutting and surface fires.

The oak type occurs on well-drained sites on all aspects and soils. Its composition, however, varies materially on different sites and in different parts of the region. Thus, chestnut oak is so much more abundant on the poorer sites as to form at times almost pure stands. On such sites it is also frequently associated with pitch pine, particularly in northwestern New Jersey and eastern Pennsylvania, where the chestnut oak-pitch pine combination is so characteristic as sometimes to be classified as a separate type. White ash, black cherry, and yellow poplar, on the other hand, are much more abundant on the better sites. Hickory is a fairly constant associate of the oaks on all sites, especially in the southern part of the region.

The type occurs chiefly in the form of farm wood lots in well-settled districts with good markets. The original forests were long ago replaced by roughly even-aged second-growth stands, which have also come in extensively on abandoned farms. These second-growth stands have been cut both frequently and heavily, and have also suffered badly from fire. As a result, they are for the most part moderately well-stocked and are composed largely of sprouts, many of them poorly formed, defective, or of inferior species. Production is therefore seldom equal to that of which the site is capable.



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ADVANCE GROWTH IN HARDWOOD STANDS

A, Advance reproduction of hardwoods, chiefly white ash, in the transition-hardwoods type (Harvard Forest). Reproduction of pine is exceedingly difficult in a stand of this character. B, A fairly mature stand in the transition-hardwoods type, Merrimack County, N. H. Note the abundant advance growth of hardwoods ready to take possession of the area when the stand is cut. C, A 15-year-old stand of second-growth sugar maple, white ash, and basswood in the Harvard Forest, consisting entirely of advance growth which came in under pure white pine and has been weeded once to favor the more valuable species and individuals. This is a striking example of the tendency for the white pine type to be replaced naturally by transition hardwoods.

THE OAK TYPE

A, A 35-year-old stand in the oak type in New Jersey after an improvement cutting (Photograph by courtesy of the N. J. Dept. Conservation and Development); B, a rather heavy thinning in an overcrowded stand in the oak type, Middlesex County, Conn. (F-93427.)

NATURAL REPRODUCTION

Although most of the trees characteristic of the oak type, except maple and birch, require a large amount of light for their best development, they are able to start and to persist for a number of years under some overhead shade. Reproduction of both seedlings and sprouts is, therefore, usually abundant in stands which are naturally rather open or which have been opened up by thinnings or other cutting.

Information on the composition and development of the reproduction under fairly typical conditions is afforded by intensive studies by the Yale School of Forestry in southern Connecticut (*30*). The stands studied consisted of about 75 per cent oak and 25 per cent other hardwoods (chestnut, formerly abundant, being eliminated). Thinnings and salvage cuttings for the removal of dead chestnut had been made over most of the area in 1902, 1905, 1908, 1910, and 1913, and over smaller portions in other years. In the winter of 1921 the remainder of the stand was cut clear at about 75 years of age. The condition of the reproduction on the area four years later is indicated in Tables 23 and 24.

TABLE 23.—*Reproduction in the oak type four years after the clear cutting of a 75-year-old stand*

Species	Good sites		Average sites		Poor sites	
	Number	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*
Oaks	3,956	35	5,331	62	3,017	70
Other hardwoods	7,443	65	3,343	38	1,275	30
Total	11,399	100	8,674	100	4,292	100

TABLE 24.—*Distribution of oaks in 4-year-old reproduction following clear cutting in the oak type*

Species	Good site	Average site	Poor site
	Per cent	*Per cent*	*Per cent*
Red oak	13	8	6
Black oak	10	6	8
Scarlet oak	26	14	11
Chestnut oak	6	53	59
White oak	45	19	16
Total	100	100	100

The much greater proportion of chestnut oak and the smaller proportion of white oak on the poorer sites is very striking. Red oak often constitutes a much larger part of the stand, particularly on good and average sites, than on the areas covered by this study. "Other hardwoods" included 22 species. Many of these, however, such as dogwood, blue beech, hophornbeam, sassafras, and serviceberry, are of minor importance and seldom reach large size. Red maple is the most common single species, constituting 19, 20, and 16 per cent, respectively, on the three sites. Chestnut reproduction was not counted because of the certainty that it would soon be killed back by the blight. Woody shrubs (viburnum, hazelnut, and witch-hazel) ran from 5,300 per acre on the good sites to 780 on poor sites. There is every indication that the oaks will again predominate in the mature stand, especially if given some relief from red maple competition.

The relative quantities of reproduction coming in before and after the clear cutting in 1921 are shown in Figure 23. That before cutting is designated as "advance growth," that after cutting as "younger reproduction." The figure brings out clearly the predominance of the younger reproduction, particularly with other hardwoods than oak. Much advance growth that started after the various thinnings undoubtedly died under the cover of the remaining stand prior to the final cutting. On good sites the advance growth ranged from 7 to 22 years in age and from 5 to 28 feet in height,

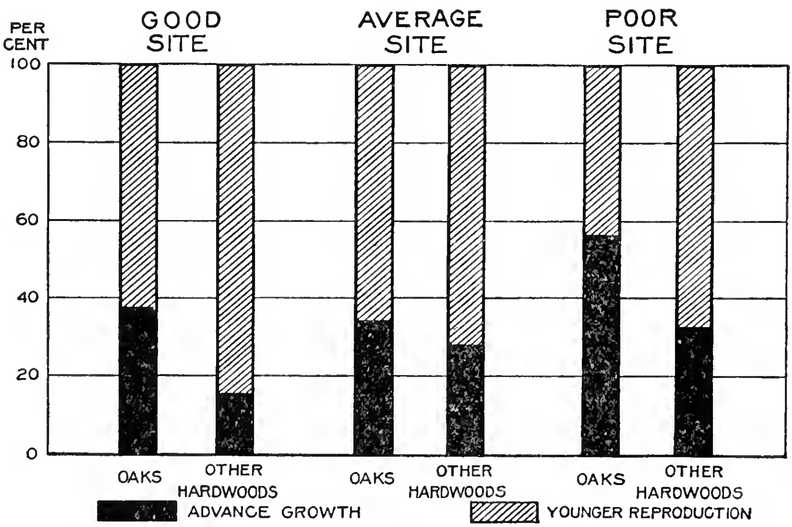

FIGURE 23.—Relative quantities of reproduction coming in before and after the final cutting in second-growth hardwood stands in Connecticut

while the younger reproduction ranged from 1 to 4 years in age and from 2 to 14 feet in height.

Figure 24 shows the relative quantities of both advance growth and younger reproduction in the form of seedlings, seedling sprouts, and sprouts. "Seedling sprouts" are those from stumps 2 inches or less at the ground line. The large proportion of seedlings and seedling sprouts—the more desirable elements in the stand—is particularly worthy of note. Sprouts are less abundant probably because they are unable to endure much overhead shade and because large stumps often fail to produce sprouts.

From 50 to 90 per cent of the seedlings and seedling sprouts and from 80 to 100 per cent of the sprouts were in a free position with apparently ample opportunity for growth. The much larger proportion of sprouts occupying a free position is undoubtedly due to their more rapid height growth in early youth. Even in the younger reproduction, however, there are enough seedlings and seedling sprouts to form an important part of the mature stand if they are able to escape subsequent suppression.

Studies in older stands indicate that seedling sprouts usually reach the same height as sprouts at between 20 and 30 years of age, and seedlings at about 40 years. Thereafter, the rate of growth of the different forms is nearly the same, with perhaps a slight advantage in favor of the seedlings. These facts indicate that seedlings coming in after the final cutting can be counted on to form an important part of the next stand, provided they have sufficient growing space to permit their unhampered development.

Most of the advance growth consisted of well-formed young trees. Poorly formed individuals were usually of sprout origin. Less than 6 per cent of the oaks were flat topped, and these showed the same

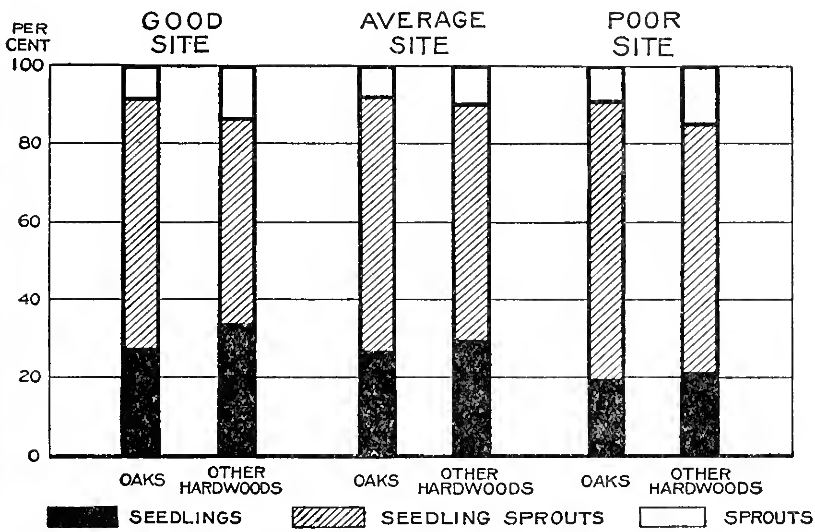

FIGURE 24.—Relative quantities of reproduction in the form of seedlings, seedling sprouts, and sprouts in second-growth hardwood stands in Connecticut

rate of growth after cutting as did those with normal or spreading crowns. But since the overhead cover on these particular areas was not dense, this growth does not necessarily imply an ability on the part of hardwoods to recover quickly from the effects of heavy and prolonged shading.

Briefly summarized, the results of these studies indicate that moderately open stands in the oak type will ordinarily be followed after clear cutting by ample reproduction of desirable species and individuals. In spite of the larger size of the advance growth and the more rapid development at first of the sprouts and seedling sprouts originating after the final cutting, there is a marked tendency for these early differences to disappear and for the dominant trees to form a practically even-aged stand of fairly uniform height. It is estimated that after 50 years of age the composition of untreated stands will be approximately as in Table 25.

TABLE 25.—*Estimated composition of untreated stands in the oak type after reaching 50 years of age*

Type of forest growth	Good site	Average site	Poor site
	Per cent	*Per cent*	*Per cent*
Oak, well formed, free seedlings and seedling sprouts	50	55	55
Other hardwoods, well formed, free seedlings and seedling sprouts	15	10	5
Sprouts, all species, and poorly formed seedlings and seedling sprouts	35	35	40

Similar results may reasonably be expected from other parts of the region, although of course with considerable variation in the relative quantities of the different species present.

METHODS OF CUTTING

Where fire and grazing are excluded, the oak type reproduces itself so readily that satisfactory results can often be obtained by any one of several methods of cutting. Consequently the choice between removing the timber in one or two cuttings, or in a series of light, successive cuttings, depends largely on whether the stand is even aged and on the wishes of the owner. In general, cuttings aimed at improving the composition and quality of the stand are fully as important as those aimed primarily at obtaining reproduction.

Clear cutting of all merchantable material to as small a diameter as possible is usually advisable in mature, even-aged stands in the oak type wherever natural reproduction is already present. This reproduction, with the additional sprouts and seedlings which are fairly sure to follow the cutting, will form the basis for a new stand and will take prompt advantage of the increased light and soil moisture made available by the removal of the older trees. The best sprouts will be produced from low stumps with smooth surfaces cut at a sufficient angle to let the water drain off. Care should be taken not to strip the bark from the stump. Logging should be done during the period of vegetative rest between late fall and early spring, since summer-cut stumps are apt to produce weak sprouts which are too tender to withstand the first frosts. Care should be taken in logging not to injure the advance growth already on the ground.

In the occasional instances where advance growth is not present, clear cutting is less satisfactory unless accompanied by planting. The absence of seedlings, the considerable distances between the clumps of sprouts that will spring from the stumps of cut trees, and the probable failure of the larger stumps to sprout at all, are likely to result in partially stocked stands with too large a proportion of sprouts, many of them poorly formed or defective. On such areas the stand can well be removed in two cuttings by the shelter-wood method. The first cutting should leave about half of the stand in the form of evenly distributed, thrifty trees of desirable species capable of bearing full crops of seed. These can then be cut clear after the reproduction is well established, say in four to eight years. If the cutting is done too soon, it will not give the seedlings so good a chance to hold their own with the less desirable sprouts; while if it is delayed too long, the advance growth will be retarded wherever it occurs under moderately heavy shade and given too much of a start in openings. Logging by the shelter-wood method may cost from $0.50 to $1 per thousand board feet more than clear cutting. On the other hand, aside from the fact that it affords much greater assurance of a satisfactory new crop, this additional cost may be more than offset by the greater value per thousand board feet or per cord of the timber removed, and by the increased growth and consequently increased value of the timber left for the second cut.

An alternative to shelter-wood cutting where advance growth is not present is to cut the stand clear and plant among the stumps 100 to 200 seedlings of the species which it is desired to favor, to fill in the open places that will not be occupied by sprouts. This method would probably not cost any more than shelter-wood cutting, perhaps less, and would give somewhat more control over the composition of the new stand.

In uneven-aged stands, light cuttings which remove only a few of the larger trees at any one time are likely to be most satisfactory. Cuttings of this sort are particularly suited to the needs of the small wood-lot owner who wishes to maintain a constant supply of timber for his own use and for the general market. The spaces left by the trees removed are filled promptly by young seedlings and sprouts, which gradually take their place in the main stand. The opportunity for development of the new growth is better if the cutting is by small groups rather than by individual trees. Selection cuttings of this sort to stimulate reproduction can often be combined to advantage with the improvement cuttings described in succeeding paragraphs.

The quality of young stands can usually be improved by cleanings. (Pl. 16, B.) These should cut back poorly formed and defective trees of all species; occasional dominants of inferior species, such as red maple, gray birch, or aspen, which are overtopping oak, white ash, yellow poplar, black cherry, or other desirable species; and dominant sprouts which are overtopping more desirable seedlings or seedling sprouts. Scarlet oak should be discriminated against because of its relatively inferior wood and its tendency to heart rot.

Cleaning should be deferred until three to five years after the final cutting in order to show up more clearly the trees which should be favored and to give then a better opportunity to retain a dominant position after they have once been freed. A second cleaning may occasionally be necessary but will require less cutting than the first. In any event, cleaning will be less expensive than in the white pine type, because the various hardwoods compete on more even terms than do pine and hardwoods. The cost should not exceed $1 to $4 per acre.

Where this cost does not appear to be justified by the probable increase in returns from the improved stand, treatment can be delayed until the trees to be removed are large enough to pay for the cost of logging (*30*). Under good market conditions, this will ordinarily be when they are between 20 and 30 years of age. The same classes of trees should be removed as in cleanings, with the object of favoring the better species and individual trees and of preventing the development of "wolf" trees. While an improvement cutting of this sort does not free the more desirable elements in the stand at as early an age as does a cleaning, its results are as a rule reasonably satisfactory. Cleanings are particularly essential where the lack of any market for cordwood precludes improvement cuttings until considerably later in the life of the stand.

By the time they are 20 to 30 years old, fully stocked stands are also usually in need of thinning, in order to prevent a falling off in the rate of growth. Where this is the case and market conditions permit, removal of undesirable trees of the sorts already specified should be supplemented by the removal of enough of the medium-sized and larger trees to give the thrifty, dominant ones which are retained ample room for development. Ordinarily, sufficient space should be left between the crowns of adjacent trees so that they will come together again in about 5 years. Subsequent thinnings can be made at intervals of 5 to 10 years and can be increasingly heavy as the stand becomes older. After the trees have reached the seed-bearing age, any opening up of the stand is apt to be followed by reproduction, so that a heavy thinning in a stand approaching maturity may virtually take the place of the first cutting in the shelter-wood method. Where frequent light thinnings are not practicable, a heavy thinning at 35 to 40 years of age is desirable.

Thinnings usually remove from 20 to 40 per cent of the total volume of the stand. On the basis of total number of trees the proportion removed varies widely with the density, but usually runs considerably higher. Since the trees taken are mostly in the smaller-size classes, the result is to raise the average diameter of the stand. Table 26 shows trees of the different crown classes taken in a typical thinning in a 46-year-old stand on a poor site in Connecticut (*19*), where 28 per cent of the total volume was removed.

TABLE 26.—*Summary of a thinning operation in a 46-year-old stand on a poor site in the oak type, Connecticut—volume removed, 28 per cent*

Crown class	Original stand per acre	Trees removed per acre	
	Number	*Number*	*Per cent*
Dominant	200	16	8
Codominant	100	16	16
Intermediate	136	68	50
Overtopped	156	140	90
Dead	132	132	100
Entire stand	724	372	51

Experiments in New York State (*41*) indicate that thinnings and reproduction cuttings may reduce by 30 to 50 years the period required by red oak, white oak, and chestnut oak to obtain merchantable diameters of 12 inches and more.

The results of thinnings in even-aged, fully stocked, crowded, but thrifty stands in New Jersey (*2*) are given in Table 27.

TABLE 27.—*Results of thinnings in even-aged, fully stocked, crowded, but thrifty oak stands, New Jersey, as shown by trees 2 inches and more in diameter*

Age of stand (years)	Degree of thinning	Stand[1]—		Average diameter of trees—		Volume per acre—	
		Before thinning	After thinning	Before thinning	After thinning	Before thinning	After thinning
		Number	*Number*	*Inches*	*Inches*	*Cords*	*Cords*
25	Light	800	450	3.5	4.0	18	14
25	Medium	800	375	3.5	4.5	18	12
25	Heavy	800	300	3.5	5.0	18	10
35	Light	700	350	4.5	5.0	25	20
35	Medium	700	300	4.5	5.5	25	17
35	Heavy	700	250	4.5	6.0	25	15
50	Light	600	275	5.0	6.0	30	24
50	Medium	600	250	5.0	6.5	30	21
50	Heavy	600	200	5.0	7.0	30	18

[1] The number of trees per acre has been evened off in all cases.

Many farmers can use thinnings as a means of providing their winter's supply of fuel, thus improving the wood lot at practically no cost except for the labor involved. Since the oak type occurs chiefly in well-settled districts in proximity to good markets, thinnings can often be made to yield a substantial cash profit. For example (*2*), the best offer one farmer in northern New Jersey could get from lumbermen was $25 per acre for all of the standing timber on a 30-acre wood lot of young mixed hardwoods. After consulting the State forester, he decided to thin the stand and to do his own cutting. By removing only trees of inferior form or species and those unduly crowding others, he made a net profit of $35 per acre and had left instead of stump land a stand of thrifty young timber which he valued at $15 per acre.

Another New Jersey example is that of a community church which made a thinning in a 20-acre wood lot of 27-year-old mixed hardwoods that were still thrifty but becoming so badly crowded that growth was slowing up. Cordwood, fence posts, and bean poles were cut at a net profit of $57 per acre, leaving a full stand of thrifty, fast-growing, immature trees for further development. Moreover, the value of the final crop will probably be more than doubled by this thinning, and the crop will mature much sooner.

The increased growth resulting from thinning is illustrated by the comparison in Table 28 of two similar plots about 25 years of age and containing about 65 per cent oak, one of which was thinned and the other left unthinned. The more rapid rate of growth of the thinned stand, its greater total volume, and the concentration of this volume in thrifty trees of desirable species, all indicate its superiority over the unthinned stand. This is emphasized by the fact that the thinning was a light one and that 36 of the trees which had been left for further growth were killed by careless brush burning.

TABLE 28.—*Comparison of thinned and unthinned 25-year-old stands in the oak type (oak 65 per cent) five years after thinning*

Treatment	Original stand			Removed in thinning		Stand five years after thinning			Average annual growth
	Trees	Average diameter	Volume	Trees	Volume	Trees	Average diameter	Volume	
	Number	*Inches*	*Cords*	*Number*	*Cords*	*Number*	*Inches*	*Cords*	*Cords*
Thinned	872	3.7	19.5	420	3.6	416	5.4	21.5	1.1
Unthinned	780	3.7	16.2			632	4.4	19.8	0.7

In the irregular stands which have resulted from the repeated culling of the better species and individuals, a combination of thinnings, improvement cuttings, and reproduction cuttings is usually needed. All dead, dying, poorly formed, large-crowned, and defective trees should come out, thus stimulating new reproduction and the development of young trees already on the ground; while the occasional dense stands of saplings and small poles should be thinned out to prevent stagnation in growth. Two or three cuttings are usually sufficient to bring even badly run-down stands into fairly good condition.

Recent sudies by the Yale School of Forestry (*31*) indicate that in southern New England, at least, hemlock gives larger yields than hardwoods and may be well worth encouraging. Wherever hemlock is present in mature stands, this can be done by leaving 1 to 10 seed trees per acre at the time of the final cutting. Good reproduction will often start from these, and the young hemlocks, which are very persistent even under a fairly dense overhead shade, can later be helped along by favoring them in cleanings, improvement cuttings, and thinnings.

On poor sites it may be worth while to convert the oak type into a coniferous or mixed type by planting white pine or Norway pine. These species give larger yields and, in such plantations as have been made, indicate their ability to thrive on soils where oak and other hardwoods do poorly. The conversion should be effected by clear cutting the existing stand and as much advance growth as possible, setting out vigorous 3 or 4 year old pine transplants, particularly in openings, and later cutting back the competing hardwoods wherever necessary until the pines are sufficiently established to take care of themselves. Two cleanings will often be necessary. The total expense will probably run from about $5 per acre when only 200 to 300 pines are planted to $20 per acre when 1,000 or 1,200 trees are used. The smaller number will result in a mixed stand of conifers and hardwoods in which the conifers will occupy a prominent place if properly favored by cleanings.

Utilization in the oak type, both in final cuttings and thinnings, is usually so close as to leave only a small amount of slash, which decays rapidly and seldom interferes with natural reproduction. No special efforts at disposal are necessary, therefore.

Cattle, horses, and sheep do much injury to oak and other hardwoods, and should be kept out of stands of all ages, except on areas where it is particularly desired to favor hemlock or pine. Here, grazing will give the conifers a much better chance for development, although at the same time it is pretty sure to result in some loss from trampling. This is likely to be more serious in plantations where only a limited number of trees is set out than on areas where natural reproduction has come in abundantly.

YIELDS

Measurements of a large number of fully stocked, even-aged stands in the oak type in Connecticut (*19*) indicated the average yields presented in Table 29.

TABLE 29.—*Yields in fully stocked, even-aged stands in the oak type, Connecticut* [1]

Age (years)	Height, dominant trees	Average diameter	Stand per acre	Volume per acre [2]	
	Feet	*Inches*	*Number*	*Cords*	*Board feet*
GOOD SITES					
30	57	5.5	575	30	1,900
40	68	7.2	405	40	5,500
50	75	8.7	310	48	9,200
60	80	10.0	260	53	12,700
70	84	11.1	220	58	15,900
75	86	11.6	210	60	17,100
AVERAGE SITES					
30	47	4.6	675	24	600
40	57	6.0	485	32	2,500
50	64	7.1	390	38	5,100
60	68	8.1	325	43	8,000
70	72	8.9	280	47	10,700
75	73	9.4	255	48	11,900
POOR SITES					
30	37	3.7	880	17	----------
40	46	4.7	650	24	1,200
50	52	5.5	515	29	2,700
60	56	6.2	430	32	4,700
70	60	6.8	275	35	6,500
75	61	7.1	345	36	7,400

[1] Figures are for trees 2 inches d. b. h., and more except as noted.
[2] Board foot volumes are for trees 9 inches d. b. h. and more.

The volume per acre in cords, which includes all trees 2 inches and over in diameter at breastheight to a top diameter of 2 inches outside bark, was first determined in cubic feet, which were changed to cords by the use of a converting factor varying from about 75 to 95 cubic feet per stacked cord, depending on the size of the average tree.

Since no figures of yield in board feet are available for the oak type, those for the chestnut type are given, with a deduction of 33⅓ per cent to allow for the considerably higher yield of the chestnut. The necessity of making so liberal a discount, which is probably none too much, gives some idea of the decreased production of stands in the sprout-hardwoods region resulting from the loss of the chestnut. Volumes of individual trees were scaled by the international rule, with a deduction of 10 per cent to allow for the wide kerf cut by the circular saw of the average portable sawmill. No allowance was made for defect. In addition to the lumber, the original chestnut stands contained from 20 to 30 cords in the form of tops and of trees too small for lumber.

The average annual growth of fully stocked stands in the oak type in Connecticut is shown in Figure 25 on the following page.

HARDWOOD-SWAMP TYPE

The hardwood-swamp type, although nowhere covering a large area, deserves mention on account of its extensive distribution throughout the Northeast. It is not distinctively characteristic of any one forest region, but is described under the oak region because of its predominance there.

Red maple is everywhere the most characteristic species. Black ash, white ash, American elm, and willows are usually present in varying amounts. Yellow birch, tamarack, and spruce are more or less common toward the north; and black gum, sycamore, swamp

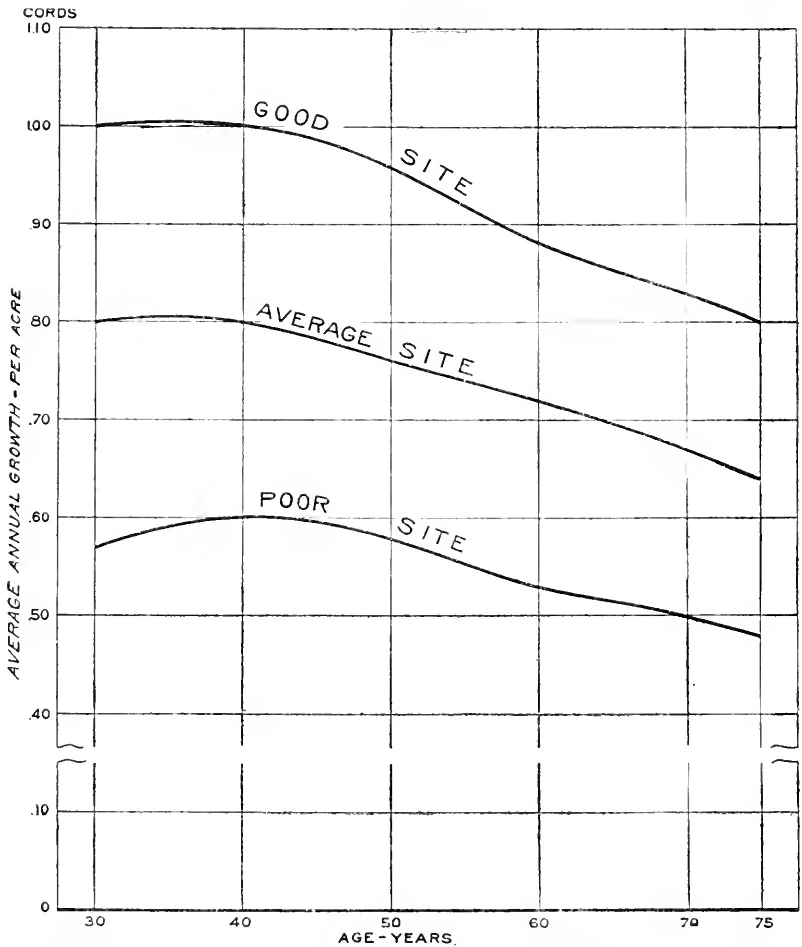

FIGURE 25.—Mean annual growth of fully stocked, even-aged stands in the oak type, Connecticut

white oak, pin oak, yellow poplar, silver maple, and river birch toward the south.

The type occupies low, wet, poorly drained sites. Although decidedly of secondary importance, it is occasionally valuable locally as a source of fuel. Clear cutting is necessary because of the danger of windfall. Satisfactory restocking usually takes place from seedlings already on the ground and from the vigorous sprouts, particularly of red maple, which follow cutting. The slash is light, decays readily, and requires no special treatment.

OTHER TYPES

The following types are discussed at length under the region indicated, and the suggestions for handling them given there apply equally well in the oak region: White pine type, white pine and hardwoods type, and gray birch type, white pine region; and mixed-hardwoods type, Allegheny hardwoods-pine-hemlock region.

ALLEGHENY HARDWOODS-PINE-HEMLOCK REGION

The Allegheny hardwoods-pine-hemlock region is essentially a transition region. It contains representatives of nearly all of the hardwoods found in both the spruce and northern hardwoods region and in the oak region, with a larger representation of such species as black cherry, black walnut, and cucumber magnolia. There is also more northern white pine and eastern hemlock than in either of the two other regions, although the amount of pine is now much less than in the original forest. The principal types are northern hardwoods, mixed hardwoods, and pine and hemlock.

The region occupies the hills of northern New Jersey and south-central and southwestern New York, and the high plateau of northern and central Pennsylvania. In New York the forest occurs largely in the form of farm wood lots, while in New Jersey and Pennsylvania there are more extensive areas of wild land. Transportation facilities are for the most part good, but the markets for small-size material are somewhat uncertain and fluctuating.

MIXED-HARDWOODS TYPE

The mixed-hardwoods type of the Allegheny region consists of a widely varying mixture of the species characteristic both of the transition-hardwoods type of the white pine region and of the oak type of the oak region. Oaks, hickories, maples, birches, beech, white ash, basswood, black cherry, and yellow poplar usually constitute the bulk of the stand. Chestnut, formerly abundant, has been virtually eliminated by the blight. White pine and hemlock are frequently common. There is also a fair sprinking of hardwoods not particularly typical of the Northeast, such as black walnut, cucumber magnolia, bur oak, and bigleaf shagbark hickory.

The type covers a large area and is of considerable commercial importance. It occurs chiefly in northern New Jersey, southern New York, and northern and central Pennsylvania, where it is found in the agricultural valleys and foothills, but seldom extends far into the mountains. Because of repeated culling and grazing, it is for the most part in rather poor condition, with comparatively open stands of inferior trees which are not making full use of the productive capacity of the site.

METHODS OF CUTTING

The mixed-hardwoods type so closely resembles the oak type in its reproduction and development that it can be handled in practically the same way. Where adequate advance growth is present, clear cutting is advisable. (Pl. 17.) Natural reproduction is, however, less abundant than in the oak type because of the greater prevalence of grazing. Where it is scarce or lacking, the exclusion of stock will ordinarily result in a few years in the establishment of a good crop of seedlings, provided the stand is open enough to admit considerable light. In dense stands, removal of some of the trees by a shelter-wood cutting or by successive selective cuttings, preferably in small groups, will also be necessary to stimulate reproduction. These successive cuttings may be so light as to maintain a continuous growth of timber from which merchantable material may be removed in small quantities every year or at least every few years. This selection system of logging is particularly adapted to uneven-aged stands and to farm wood lots.

The composition and quality of young stands can be improved by a cleaning, which should be made from three to five years after the final cutting. As in the oak type, the less desirable species, particularly red maple, the poorer trees of all species, and the sprouts which are overtopping seedlings or seedling sprouts, should be cut back to favor the better elements in the stand. As soon as the trees are large enough to have a value as cordwood, usually between 20 and 30 years of age, a similar improvement cutting is desirable. This may either be in place of, or preferably in addition to, an earlier cleaning.

Thinnings to maintain a high rate of growth are also important as soon as overcrowding begins. These should aim to leave a uniform stand of thrifty, well-formed trees of desirable species with ample growing space. Because of the generally favorable market conditions, they can usually be made without loss, and often at a substantial profit. (Pl. 18.)

An experiment by the department of forestry of the New York State College of Agriculture illustrates the advantages of thinning (*23*). Three plots were laid out in 1914 in an even-aged, 25-year-old stand made up of both seedlings and sprouts. A wide variety of hardwoods was present, including sugar maple, red maple, basswood, hickory, elm, red oak, white oak, white ash, yellow poplar, butternut, and black cherry. The plots were so selected as to be as similar as possible in composition, age, height, and density. One plot was heavily thinned, a second lightly thinned, and the third left unthinned as a check. Five and ten years later the plots were remeasured; the results are given in Table 30. It is evident from these figures that both diameter growth and volume growth increased in proportion to the severity of the thinning. The increase in volume is particularly striking when considered in relation to the amount of growing stock left after thinning. Thus, the heavily thinned stand, with only 55 per cent of the volume of the unthinned stand, not only produced a larger total volume of wood, but on a percentage basis grew more than twice as fast.

TABLE 30.—*Results of thinning in an even-aged, 25-year-old stand in the mixed-hardwoods type of the Allegheny hardwoods-pine-hemlock region, 1914–1925*

Character of plot	Trees per acre				Diameter of average tree			
	Before thinning	After thinning			Before thinning	After thinning		
		1914	1919	1921		1914	1919	1924
	Number	*Number*	*Number*	*Number*	*Inches*	*Inches*	*Inches*	*Inches*
Unthinned	652	652	620	580	4.62	4.62	5.32	5.91
Lightly thinned	660	376	376	376	3.70	4.80	5.74	6.34
Heavily thinned	760	344	332	328	3.97	4.68	5.85	6.90

Character of plot	Volume per acre				Average annual growth per acre			
	Before thinning	After thinning			1914–1919		1919–1924	
		1914	1919	1921				
	Cords	*Cords*	*Cords*	*Cords*	*Cords*	*Per cent*	*Cords*	*Per cent*
Unthinned	17.4	17.4	22.0	26.6	0.90	5.2	0.93	4.2
Lightly thinned	19.1	10.9	15.6	22.1	.94	8.6	1.31	8.0
Heavily thinned	20.9	9.5	14.3	22.6	.96	10.1	1.67	11.7

That thinnings may also yield an immediate financial return is indicated by the experience already cited, of the community church in New Jersey which made a thinning in a badly crowded 20-acre wood lot of mixed hardwoods and realized a net profit of $57 per acre, leaving a stand of thrifty, fast-growing trees, whose final development will be much more rapid and will result in a final crop probably more than double what it would otherwise have been.

As in the other hardwood types, slash disposal is not necessary to obtain satisfactory reproduction. Of far greater importance is the prevention of grazing, which does much damage to young growth and tends toward soil erosion.

YIELDS

No figures of yield are available for this type. It is probably safe to assume, however, that the production of fully stocked stands will at least equal and probably exceed that in the oak type given on page 89. Measurements of fully stocked stands of ash on good sites, chiefly in the Central States, show considerably higher yields (*45*).

PINE-HEMLOCK TYPE

The pine-hemlock type occurs chiefly in the more rugged parts of south-central New York and north-central Pennsylvania, although it also extends southward along the Alleghenies and other near-by mountain ranges. Northern white pine and eastern hemlock, occasionally pure but more commonly in varying degrees of mixture, are the characteristic species. (Pl. 19.) Hardwoods are often present and may include any of the species typical of the northern hardwoods or mixed hardwoods. In fact, the type tends to blend with the northern-hardwoods type toward the north and at higher elevations, and with the mixed-hardwoods type and oak type toward the south and at the lower elevations.

The pine-hemlock type was originally the most important type commercially in northern Pennsylvania, and furnished the bulk of the lumber cut in that State during the early days. In places the stands were so dense and cast such a heavy shade as to acquire the nickname of the "black forest." These have been steadily logged until to-day only a few remnants of the virgin forest are left. Moreover, lumbering has often been followed by fire, with the result that extensive areas once occupied by valuable pine and hemlock are now covered by comparatively worthless aspen, pin (fire) cherry, and "scrub" oak.[7]

METHODS OF CUTTING

Wherever adequate reproduction is already present, either in virgin or second-growth stands, clear cutting will give satisfactory results. Where it is not present, as is likely to be the case in fully stocked stands, the shelter-wood method should be used. The first cutting is fairly certain to induce good reproduction of pine and hemlock, and also of such hardwoods as may be represented, and can usually be followed in from 5 to 10 years by the removal of the remaining stand. Care should be taken in the final cutting to avoid injury to the conifers and at the same time to cut back as much as possible the advance growth of hardwoods, in order to give the former every opportunity for development.

Immature stands can be increased considerably in value by cleanings and thinnings similar to those recommended for the pine and hardwoods type. White pine should be favored as the fastest growing and most valuable species, although some admixture of hemlock and hardwoods is advisable as a means of improving the quality of the pine. Hemlock is an even more desirable associate than hardwoods, because it demands less room, grows less rapidly in height, and is able to persist for many years under even moderately dense shade. There is, therefore, less danger that it will overtop or crowd out the pine, while at the same time it is equally effective in bringing about natural pruning. Intensive measures are, however, less practicable than in the white pine region, because of the usual occurrence of the pine and hemlock type in sparsely settled districts with poor markets for fuel wood.

The coniferous slash resulting from either clear cutting or shelter-wood cutting is usually so abundant and forms such dense piles as to interfere seriously with the establishment of reproduction over a large part of the area. Both pine and hemlock tops should, therefore, be gotten out of the way by burning, preferably in small piles as the logging proceeds and when the woods are moist enough to prevent fire from running. Thinnings result in comparatively little slash where the material removed can be utilized and even where it can not, burning is hardly feasible because of the danger to the remaining stand. Any special disposal of hardwood slash is also unnecessary.

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[7] Although bear oak is the standard name for *Quercus ilicifolia* as given in the Check List of the Forest Trees of the United States (*47*), that species is so generally known as "scrub" oak throughout the Northeast that that common name is used in this bulletin.

YIELDS

Accurate figures on yields are not available, but in well-stocked stands these can be expected to correspond fairly closely to those in the white pine type already given.

OTHER TYPES

On the extensive areas now occupied by aspen, pin (fire) cherry, and scrub oak, the great problem is to hasten the reversion of this temporary transition type to the original pine and hemlock. The problem is similar to that offered by the gray birch type in the white pine and oak region, but is more difficult because of the fact that market conditions usually make the profitable utilization of the inferior species impracticable. Where natural reproduction of desirable species is present, it will ordinarily succeed eventually in reclaiming the area; but the process can be hastened by lopping back the overtopping inferior hardwoods at a probable cost of from $2 to $5 per acre. Where natural reproduction is not present, the only way to restore the original type within a reasonable time is by the still more expensive method of planting and subsequent cleaning.

The following types are discussed at length under the region indicated, and the suggestions for handling them given there apply equally well in the Allegheny hardwoods-pine-hemlock region: Northern hardwoods type, spruce and northern hardwoods region; white pine type, white pine region; and oak type, oak region.

PINE AND OAK REGION

The pine and oak region is characterized by either pure or mixed stands of pines and oaks. The different species vary rather widely in abundance in different parts of the region, but pitch pine and scrub oak are usually prominent. In New England post oak is also a characteristic species. In New Jersey shortleaf pine, white oak, and black oak are common, and more or less backjack oak, post oak, and scarlet oak are found. Southern white cedar is locally abundant in swamps along the coast. The principal types are pine, pine-oak, oak, and southern white cedar.

The region occupies Cape Cod, southern Long Island, and southern New Jersey. There are a few communities which certain types of intensive farming have made very prosperous, but the light soils have prevented general agricultural development, and the population is much less dense than in the adjacent oak region. Great strides have been made in recent years toward control of the forest fires which formerly were frequent and had reduced both vegetation and soil to very poor condition.

PINE TYPE

The pine type in the pine and oak region is characterized on Cape Cod and Long Island by pitch pine, and in southern New Jersey by pitch pine, or shortleaf pine, or both species in mixture. On burned-over areas scrub oak is nearly always abundant. Various other oaks are occasionally present. The type is confined chiefly to the poorest, dryest sands. Repeated burning has increased the original representation of pitch pine and scrub oak and has left the majority of stands in poor condition, with slow-growing, unhealthy, deformed trees. Pine has been able to survive partly because its light, wind-blown seeds give it an advantage in restocking cut-over areas, but still more because of the ability of both pitch pine and shortleaf pine to sprout after cutting or fire. The sprouts are, however, usually weak unless they come from such small stems as to be classed as seedling sprouts. Sprouts from larger stumps, although they live long enough to produce fertile seed, seldom make thrifty trees of any size.

METHODS OF CUTTING

A fair amount of pine reproduction is usually present in moderately open stands from which fire has been kept out. Here, clear-cutting will afford the full light necessary for the best development of both pitch pine and shortleaf pine. In dense stands, on the other hand, seedlings are usually scarce because of their intolerance of overhead shade and their inability to start on a thick layer of pine needles. Here, a heavy shelter-wood cutting which removes at least 50 to 70 per cent of the crown cover will stimulate reproduction by admitting ample light and hastening the decomposition of the needle litter (*2*). The remaining stand can be cut as soon as the new crop is well established.

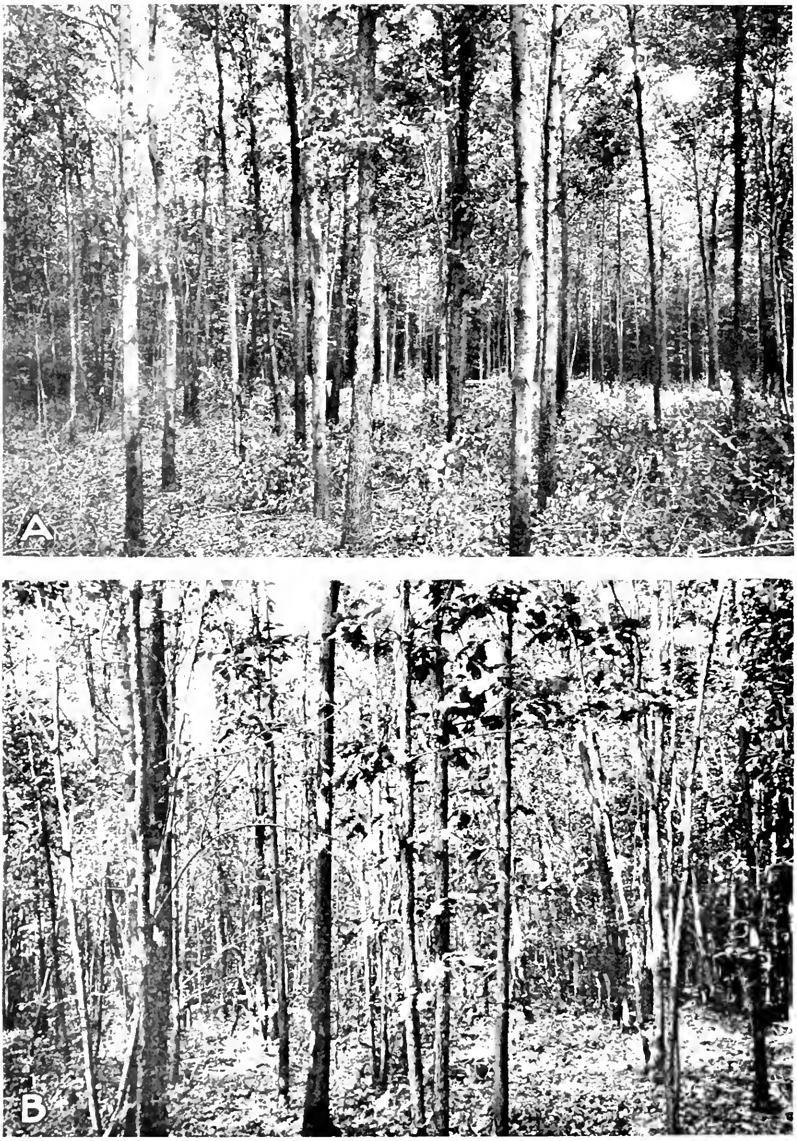
Seed trees, although somewhat less certain to produce fully stocked stands, can often be used in place of the shelter-wood method with satisfactory results. Because of the great danger of fire, they can also be left to good advantage after clear-cutting or after the final shelter-wood cutting, even where plenty of seedlings are already present, in order to afford a supply of seed for restocking the area in case the existing crop should be destroyed by fire. There should be from 5 to 10 windfirm trees per acre with sufficient crown to produce abundant seed. Where shortleaf pine is present, it should be favored over pitch pine because of its better form and superior wood.

Where pine tops can be utilized for fuel, the quantity of slash left is so small that no disposal is necessary aside from scattering as uniformly as possible. Elsewhere, the quantity may be sufficient to warrant burning, particularly in view of the extremely high fire hazard. Burning in this type is itself more or less hazardous, however, and should be done, if at all, when the danger that fire will escape is least, as for example in wet weather, when snow is on the ground, or after nightfall. If burning is not done, lopping and scattering will hasten the decay of slash and reduce its interference with reproduction.

Cleaning is unnecessary in young stands of either pitch pine or shortleaf pine, both of which on the dry soils characteristic of this type are able to hold their own with such hardwoods as may be present. Thinning is, however, advisable in the crowded stands which sometimes occur on unburned areas, provided the material removed can be marketed without loss. Such thinnings should be made as early as possible and never later than 40 or 45 years of age. Dominant, healthy trees, particularly of shortleaf pine, should be favored by the removal of poorly formed, defective, and suppressed

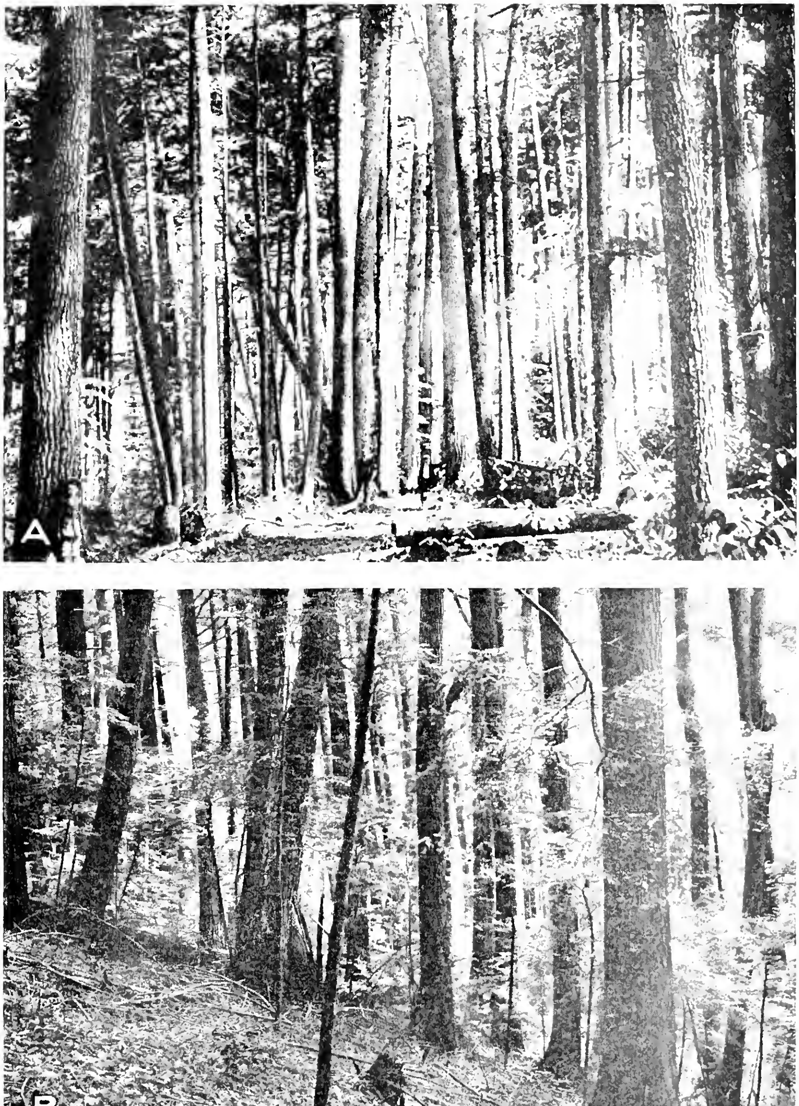
IN THE MIXED-HARDWOODS TYPE

A, A fairly mature stand with good advance growth; B, an improvement cutting in a similar stand. The absence of reproduction is probably due to grazing.



A PROFITABLE THINNING OPERATION

This thinning (A) yielded a net profit of $57 per acre and left the stand in better condition than before (B).



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IN THE PINE-HEMLOCK TYPE

A, A mature stand of pure white pine in Clearfield County, Pa.; B, a stand of practically pure hemlock, with hemlock reproduction, in Otsego County, N. Y.

trees, together with enough larger ones to give them plenty of room for development. The quantity of material removed and the stands thus obtained, in actual thinnings of fully stocked, crowded, but thrifty stands of shortleaf pine in New Jersey (*2*), are given in Table 31.

TABLE 31.—*Data on thinnings in fully stocked, crowded, thrifty stands of shortleaf pine in New Jersey*[1]

Average age of stand (years)	Degree of thinning	Trees per acre		Average diameter of trees		Volume per acre	
		Before thinning	After thinning	Before thinning	After thinning	Before thinning	After thinning
		Number	*Number*	*Inches*	*Inches*	*Cords*	*Cords*
15	Light	2,000	1,200	3.0	3.5	12	9
15	Moderate	2,000	1,000	3.0	4.0	12	8
20	Light	1,800	900	3.5	4.5	18	15
20	Moderate	1,800	750	3.5	5.0	18	13
25	do	1,400	600	4.0	6.0	25	18
25	Heavy	1,400	500	4.0	6.5	25	15
35	Moderate	800	400	5.0	7.0	30	20
35	Heavy	800	300	5.0	7.5	30	17
45	Moderate	450	225	6.0	8.0	35	24
45	Heavy	450	175	6.0	8.5	35	21

[1] Figures are for trees 2 inches and more in diameter at breastheight.

Thinnings not only improve the condition of the stand and result in increased growth, but under favorable market conditions may prove decidedly profitable. (Pl. 20.) The State forester of New Jersey (*2*), for example, reports a 35-year-old stand of shortleaf and pitch pine from which 6 cords of wood per acre were removed at a profit, with the probable result of increasing the yield at 50 years of age from about 15,000 board feet to at least 20,000 board feet per acre.

YIELDS

No figures for yields are available other than those given in Table 31, but they will undoubtedly run much lower than in the white pine type. Properly stocked stands should, however, yield at least 20,000 to 25,000 board feet per acre at 50 or 60 years of age.

PINE-OAK TYPE

The pine-oak type resembles the pine type except for the much larger proportion of oak. This comes in more freely on the slightly better, although still poor soils, and may form 50 per cent or even more of the stand. On Cape Cod, post oak is the principal species of oak, while in New Jersey black, blackjack, white, chestnut, post, and scarlet oaks are more common. Scrub oak frequently appears after fires in both parts of the region.

On the whole, the mixture is usually a desirable one. Pine, especially shortleaf pine, produces more lumber, but oak helps to improve the quality of the soil and yields more and better cordwood from thinnings. If fire is kept out, the natural tendency is for the oak to increase in abundance.

Clear cutting results in the vigorous production of oak sprouts, which are likely to suppress such advance growth of pine as may already be present. (Pl. 21, A.) The most effective way to maintain or increase the proportion of conifers is to plant a few hundred pines in the openings among the stumps after clear cutting and to give them an opening to develop by cutting back the competing hardwoods. Whether or not this procedure costs more than it is worth depends on how well stocked a stand of desirable hardwoods might otherwise be expected on the area if no cutting were done.

Thinnings in crowded stands are advisable wherever there is a market for the product. In general, the better trees should be retained, irrespective of species, but with a tendency, as between two equally good trees, to favor pine, particularly shortleaf pine.

Mention should be made here of the pitch pine-chestnut oak combination which commonly occurs on the mountain slopes of northwestern New Jersey and eastern and southern Pennsylvania, and which has already been referred to in the discussion of the oak type. This combination differs from the pine and oak type of New Jersey in that shortleaf pine is absent and that chestnut was formerly abundant. It also occurs on better soils, and produces larger yields. Pitch pine probably attains its best development in this combination, which is often recognized as a separate type and should be distinguished from the pine-oak type of the coastal plain.

SCRUB-OAK TYPE

The scrub-oak type is characterized by the predominance of scrub oak, and occurs on areas from which other species have been largely eliminated by successive fires. It is common not only throughout the pine and oak region, but also in eastern Pennsylvania, where it is the prevailing type in the anthracite coal fields, and in parts of the bituminous coal fields.

Scrub oak sprouts so vigorously that it is able to perpetuate itself indefinitely on areas that are repeatedly burned. If fire is kept out, however, various other oaks, pitch pine, and in New Jersey shortleaf pine, gradually creep in and replace it. With adequate protection from fire the type is, therefore, a strictly temporary one, although if there are no near-by seed trees of more valuable species it may be many decades before these are able to obtain even a foothold.

Where pine and better oaks are coming in naturally these species can be hastened by cutting back the scrub oak. Elsewhere conversion of the type to a more valuable one can be effected by burning followed by the planting of shortleaf pine. At least one subsequent cleaning is likely to be necessary to insure the establishment of the planted trees. Either of these methods of converting the scrub-oak type to something better will probably cost from $8 to $15 per acre. Whether this investment can be justified in view of the probable returns is perhaps open to question. The scrub-oak type may, therefore, be one where intensive forestry is at present impracticable and where, aside from keeping out fire, nature must be allowed to take its course.

OAK TYPE

The oak type in this region usually differs from that in the oak region in containing a smaller proportion of other hardwoods. The method of treatment can be the same, but yields are apt to be somewhat less because of the poorer soils.

SOUTHERN WHITE CEDAR TYPE

In the Northeast the southern white cedar type occurs only in the swamps of southern New England and the coastal plain of New Jersey. It is characterized by the predominance of southern white cedar, which is usually pure, although occasionally mixed with red maple and other scattering hardwoods.

Many areas formerly occupied by the type have been converted after cutting into cranberry bogs. Although of restricted occurrence, it is locally of considerable importance because of the high value of southern white cedar wood. (Pl. 21, B.) Its management will be discussed in a bulletin now in preparation.

PLANTING

Clear cutting of mature stands followed by planting of the cut-over areas constitutes a possible method of starting a new crop in any type. Its chief merits are simplicity and reasonable certainty of success. On the other hand, it is expensive; fail places often occur which must be filled by replanting; and cleanings are usually necessary to prevent suppression of the planted trees by undesirable species. Unless the nursery stock used comes from locally produced seed, there is also danger that it will not be so perfectly adapted to the site as native seedlings are. Wholesale planting after cutting is, therefore, seldom advisable save as a last resort.

In most cases the wisest course is to get the best possible natural reproduction by one of the methods described, and to supplement this by planting the unstocked patches which are apt to occur even with the most careful handling. Since the total area involved is usually not large, planting offers an effective and not unduly expensive means of making these productive and thereby increasing the final yield. There is no doubt that planting, which has so far been resorted to mainly for reforesting areas without tree growth, might advantageously be used much more widely in connection with natural reproduction for the growing of full timber crops.

Planting for this purpose should, of course, be done in accordance with the general principles outlined in connection with the reforestation of completely idle lands (pp. 20–24). The species used in any given type should ordinarily be one or more of those which it is desirable to favor in the natural reproduction. Such hardy and valuable conifers as white pine, Norway pine, and Norway spruce can, however, often be planted to advantage on sites to which they are adapted even though they were not present in the original stand. Wherever white pine is used it must be protected from the blister rust by the eradication of currant and gooseberry bushes.

Planting should be done if possible soon after the removal of the previous crop so as to enable the planted trees to develop on even terms with the natural reproduction. After the new stand is well started, there is little use in planting openings which do not have a diameter equal to at least twice the height of the surrounding trees. Cleanings to assure the planted trees ample opportunity for free development are even more important than with natural reproduction because of the greater investment represented in the former.

Planting may also be used to convert a comparatively worthless type into one of valuable species. Specific examples which have already been mentioned are the replacement of gray birch by white pine and of scrub oak by shortleaf pine or loblolly pine. This is, of course, much more expensive than the supplementing of desirable reproduction, and one or two cleanings will usually be necessary to assure the satisfactory development of the planted trees.

SUMMARY OF MEASURES NECESSARY TO PRODUCE FULL TIMBER CROPS

In addition to the adequate protection of all forest land from fire, insects, and disease, the production of full crops of timber requires such treatment of existing forests as will insure the best possible yield of desirable species. Silviculture is so essentially a local matter that this treatment will vary more or less widely for each forest type and even for each individual stand. Certain broad principles of rather general application can, however, be recognized.

REPRODUCTION CUTTINGS

Mature stands in any type should be harvested in such a way as to assure the perpetuation of the forest. Where advance growth of desirable species is already present, this can be done by the clear cutting of all merchantable material. Where advance growth is not present, reproduction can be stimulated by the use of the shelter-wood method, under which about half the stand is removed in a first cutting and the remainder 5 to 10 years after the new crop is well established. The shelter-wood method can also be used to bring in desirable species that are not well represented in the advance growth, as for example in the white pine type, where hardwood seedlings are apt to be much more abundant than white pine. Selection cutting, or the removal of occasional trees or groups of trees in different parts of the stand, is often desirable in uneven-aged stands and particularly in farm wood lots. Where satisfactory natural reproduction does not follow cutting, planting can advantageously be undertaken, provided the work is done soon after the final removal of the mature stand.

Care should be taken in logging to avoid injury to all young trees which should form part of the next crop. On the other hand, inferior species and poorly formed, unthrifty trees, both in the residual stand and in advance growth, may well be cut at the time of logging to favor those of more promise. In the white pine types it is even worth while to make a special effort to cut back the young hardwoods in order to give the white pine seedlings a better chance for development. In practically all types logging damage to conifers is to be particularly avoided.

SLASH DISPOSAL

The dense piles or windrows of slash which are commonly left after logging often cover a sufficient area to interfere seriously with the establishment of fully stocked stands. Wherever market conditions permit, this difficulty can be largely avoided by utilizing as much as possible of the slash for fuel and scattering the rest. Coniferous slash is particularly dangerous because it packs down closely and decays slowly. In places where it is dense and utilization is impracticable, disposal of coniferous slash by burning, preferably as logging proceeds, is, therefore, advisable. Hardwood slash is so much more open and decays so much more rapidly that no special disposal is generally necessary.

IMPROVEMENT CUTTINGS

Cultural measures are fully as important for young stands as is their establishment. The first work of this sort can be done to excellent advantage when the new crop is only a few years old. It should aim to improve the composition and quality of the stand by cutting back the undesirable species and individuals. This will give a better opportunity for the development of the more desirable elements which might otherwise be badly suppressed or completely eliminated. Because of their slow initial growth, conifers particularly need to be favored in this way. Two or even three cleanings may, in fact, be necessary to enable conifers to reach a height where they can hold their own with the more aggressive hardwoods.

Very similar improvement cuttings can be made as soon as the stands are old enough so that the material removed can be used for fuel. Near good markets this will ordinarily be between 20 and 30 years of age. At about the same time, well-stocked stands become so crowded as to require thinning in order to prevent a falling off in their rate of growth. Trees which are undesirable from the standpoint of species, form, vigor, or position in the stand should be removed, together with enough of the better trees to give those that are left ample growing space. The thinning can then be repeated when the stand has again become crowded, say in 5 to 10 years. Frequent light thinnings are better than infrequent heavy ones. By maintaining the rate of growth of the stand and concentrating this growth on the best trees, thinnings increase the final return and also yield an intermediate profit from the material removed.

GRAZING

Cattle, horses, and sheep do so much damage to young hardwoods that they should be excluded from stands of all ages in which hardwoods are to be favored. On cut-over areas where conifers are to be favored, limited grazing may, on the other hand, be an advantage by helping to reduce competition from the hardwoods. Although it will usually result in some injury to the conifers from trampling, its chief effect is to serve as a very crude sort of cleaning.

YIELDS

Yields of fully stocked natural stands indicate the minimum that can reasonably be expected under intensive forest management.

With properly handled cuttings, cleanings, and thinnings in the new forest it should be possible to exceed these yields both in the volume and quality of the final product. Figure 26 shows the mean annual growth in cubic feet of fully stocked natural stands of several

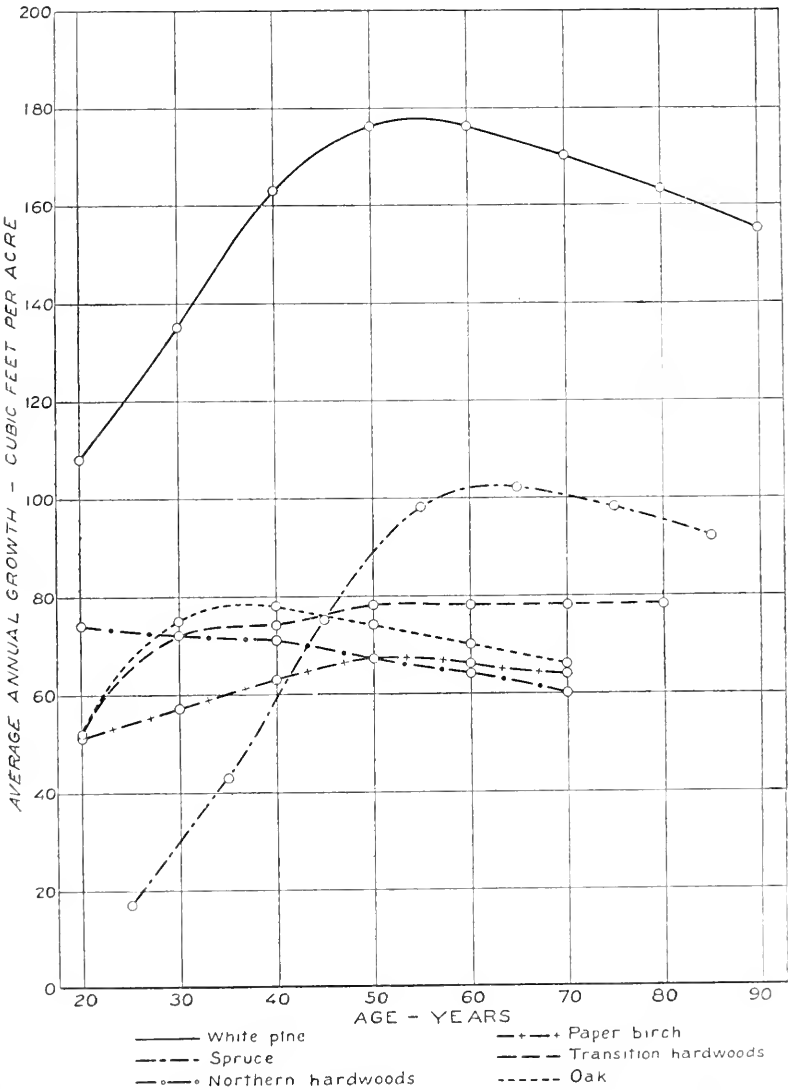

FIGURE 26.—Average annual growth of various forest types on the best sites

representative types on the best sites. While the figures are not wholly comparable, they give some idea of relative productivity. The great superiority of white pine and the practical uniformity of the hardwood types are particularly striking.

TREATMENT BY FOREST TYPES

SPRUCE

In pure stands of spruce clear cutting is advisable where advance growth is abundant. Where advance growth is scanty, a third to a half of the crown canopy should be removed first and the remainder of the stand a few years later, after the reproduction following cutting has become well established. On steep slopes, however, partial cutting is so likely to result in serious windfall that the only real alternative to clear cutting is to leave the stand intact as a protection forest.

In mixed stands of spruce and northern hardwoods, clear cutting of both conifers and hardwoods to the lowest merchantable diameter is desirable, provided the advance growth of spruce and balsam fir is abundant. Where such growth is lacking, or where the hardwoods are not merchantable, there is little hope of maintaining a large proportion of conifers in the new stand by reproduction cuttings alone.

Special care should be taken in all logging operations to do as little injury as possible to advance growth of spruce and balsam fir. Dense conifer slash interferes seriously with the establishment and development of reproduction and can advantageously be disposed of by burning in small piles as cutting proceeds during fall or winter logging. In spring and summer logging, burning must be deferred until late fall or early winter, when heavy rains or snows make it safe.

The development of young spruce and balsam fir after logging can be greatly aided by cutting back the competing hardwoods at a cost of about $2 an acre. The young conifers can also be favored by the girdling of large hardwoods which would otherwise suppress them. This operation can be performed at a cost of $1.25 to $1.50 an acre. Girdling should be limited strictly to hardwoods which are actually interfering with the development of good coniferous reproduction, and which, because of poor quality or inaccessibility, are practically certain to have no commercial value in the near future. The thinning of overdense young stands is desirable wherever the value of the material removed will pay for the cost of the thinning.

Damage from the spruce bud worm can be lessened by reducing the proportion of balsam fir and by cutting out infestations as soon as they appear.

Yields per acre in pulpwood at 70 years run from 36.5 cords on poor sites to 69.7 cords on good sites. Board-foot yields are relatively low because of the small diameters characteristic of fully stocked stands of spruce. They range from 8,800 feet per acre on poor sites to 31,800 on good sites at 70 years.

NORTHERN HARDWOODS

Old-growth stands of northern hardwoods can ordinarily be handled to best advantage by cutting all merchantable trees down to an average diameter of about 12 or 15 inches. This will permit the establishment of new reproduction and the development of the remaining stand, which can later be removed in successive partial cuttings. Clear cutting, which is satisfactory wherever advance growth is abundant, is seldom feasible economically because of the absence of a market for the trees. When practiced, it should remove the stand as completely as possible, including small saplings.

Second-growth stands are usually even aged and near enough a market to permit complete utilization. When well stocked they have a rather uniform, dense crown cover which tends to prevent abundant reproduction. Under these conditions the removal of the stand in two cuttings by the shelter wood is advisable. Irregular and uneven-aged second-growth stands can be handled by selection cutting.

No special disposal of slash after logging operations is necessary. Grazing of all sorts is highly injurious to hardwood reproduction and should not be permitted in either old-growth or second-growth stands. Cleanings to favor the best individuals of the desired species and thinnings to increase the growth in overdense stands are theoretically desirable but economically impracticable in a large part of the type.

Yields of well-stocked second-growth stands on good sites may run as high in cords as the stand is years old. Although not now common over extensive areas, they should be possible of attainment under intensive forest management. After 60 years of age the total growth increases slowly.

BIRCH-ASPEN

The birch-aspen type characteristically occurs on burned-over land as a transition type which the owner is only too glad to have revert to the original type of spruce or northern hardwoods. Since advance reproduction of the more valuable species is usually present, the change back to the original type can most easily be effected by clear cutting the birch and aspen as soon as they reach merchantable size. No special disposal of the slash is necessary. Stands of average density can be expected to yield about 17 to 26 cords per acre at 50 years of age.

WHITE PINE

On good soils white pine attains its best development in mixture with the better hardwoods, such as red oak, white ash, sugar maple, and yellow birch, which do not thrive on poor soils, where pure stands of white pine are usually the objective. In both cases satisfactory reproduction can best be obtained by the shelter-wood method of cutting. The first cutting should remove from 40 to 50 per cent of the crown canopy and, if practicable, should be made while there is no snow and the litter and humus may be torn up as much as possible. The remainder of the stand should be cut clear when the reproduction resulting from the first cutting is from 4 to 6 years old. On areas where the soil is light and the stand is more or less uneven aged, a heavier first cutting can be made to favor the smaller trees, and the second cutting can be deferred a few years longer. Seed trees, while occasionally satisfactory, are a less dependable method of reproduction than the shelter-wood method.

The pine slash resulting from cutting in the white pine types is usually heavy, decays slowly, and interferes seriously with the establishment of well-stocked stands. Where market conditions do not permit its sale for fuel it should be burned in small piles or in windrows. This can be done at a cost of from $0.50 to $1.25 for every thousand board feet of timber cut. No special disposal of hardwood slash is necessary.

Cleanings to free young white pines and desirable hardwoods from suppression by less desirable hardwoods, such as red maple, gray birch, and aspen, are very important. The "weed" species should ordinarily be cut back when they are about 3 to 5 years old and 5 to 8 feet high. On good soils a second cleaning will usually be necessary in about five years when the hardwoods will again be overtopping the pine. The total cost may run from $2 to $8 per acre. The limited grazing of cattle or sheep, which browse on the hardwoods, tends to favor the pine, and thus to serve as a crude form of cleaning.

Thinnings of overdense stands should ordinarily be made by the time the trees are 20 to 25 years, and may be repeated at 5 to 10 year intervals. Spaces of 3 to 5 feet between the crowns of the trees left will ordinarily be completely filled within five years. Judicious thinning may readily increase the volume of the stand 20 per cent as compared with unthinned stands.

White pine should be protected from the blister rust by the complete eradication of cultivated black-currant bushes and by the removal of all other currant and gooseberry bushes, both wild and cultivated, within 900 feet of adjacent stands. Where the pales weevil is a serious menace, the only real safeguard is to obtain natural reproduction of white pine in such abundance that a loss of 50 to 75 per cent will still leave enough seedlings to form a satisfactory stand. Pine plantations can not safely be set out on cut-over pine areas until the third year after cutting. Some protection can be afforded against serious injury by the white pine weevil by growing white pine in comparatively dense young stands and in mixture with other species, or by removing infested leaders and either burning them or placing them in tight barrels covered by a wire mesh.

Yields of fully stocked second-growth stands of white pine at 60 years of age range from 33,600 board feet per acre on poor sites to 60,200 board feet on good sites.

TRANSITION HARDWOODS

In even-aged stands satisfactory natural reproduction in the transition-hardwoods type can ordinarily be obtained either by clear cutting or by shelter-wood cutting. Clear cutting is preferable where advance reproduction is abundant, shelter-wood cutting where it is scanty. The first of the two shelter-wood cuttings should take 40 to 50 per cent of the crown canopy, the remainder being removed as soon as seedling reproduction has become well established. In uneven-aged stands selection cuttings which remove only a few trees at a time and thus give the new stand a chance to come in gradually are both practicable and desirable.

No disposal of the slash is necessary. Grazing of either cattle or sheep should be entirely excluded.

Clearings that favor the best individuals of desired species will improve the quality and composition of the stand. Thinnings are advisable from 20 years on, wherever there is a market for the material removed.

Yields run at 60 years of age from about 40 cords per acre on average sites to about 55 cords on good sites. At the same age the lumber content varies from 8,700 board feet on average sites to 15,600 board feet on good sites, with additional cordwood.

GRAY BIRCH

The chief object of cutting in the gray birch type is to hasten its reversion to a forest of more valuable species. This can be done by clear cutting as soon as the stand reaches merchantable size, since this will allow the advance reproduction of white pine and desirable hardwoods, which is ordinarily present, to take possession of the area. Subsequent clearing may be necessary to enable the advance growth to hold its own with the vigorous sprouts from the stumps of the cut trees. Where advance growth is not present, conversion to the white-pine type can be effected by planting, followed by removal of the gray birch stand three to eight years later. The slash is light and decays quickly, so that no disposal is necessary.

Yields are about 20 cords per acre at 25 to 30 years of age, after which the short-lived stands break up rather rapidly.

OAK

In even-aged stands clear cutting is advisable where advance growth is abundant, shelter-wood cutting where it is scanty. The first cutting should leave about half of the stand in the form of evenly distributed thrifty trees of desirable species. These can then be cut clear in four to eight years after the reproduction resulting from the opening of the stand is well established. In uneven-aged stands reproduction can be obtained by the selection method of cutting, which retains some merchantable material constantly on the ground. This method of cutting is particularly adapted to the small wood lot and can often be combined to advantage with improvement cuttings.

No special disposal of slash is necessary. Grazing should be completely prohibited, since it is almost certain to interfere seriously with hardwood reproduction.

The quality of young stands can be improved by cutting back poorly formed and defective trees of all species, dominant individuals of inferior species which are overtopping desirable species, and dominant sprouts which are overtopping more desirable seedlings or seedling sprouts. Clearings of this sort should ordinarily be made three to five years after the final cutting of the stand and may need to be repeated a few years later. The cost should not exceed \$1 to \$4 per acre. In dense stands frequent light thinnings are desirable after the stand is 20 to 30 years old. Where these are not practicable because of poor market, a heavy thinning can advantageously be made at 35 to 40 years of age.

Yields at 50 years of age range from 29 cords per acre on poor sites to 48 cords per acre on good sites. At 75 years the lumber yield averages 7,400 board feet on poor sites and 17,100 board feet on good sites.

HARDWOOD-SWAMP

Clear cutting is necessary in the hardwood-swamp type because of the danger of windfall. Satisfactory restocking usually takes place from seedlings already on the ground and from the vigorous sprouts, particularly of red maple, which follow cutting.

MIXED HARDWOODS

The mixed-hardwood type resembles the oak type so closely in its reproduction and development that it can be handled in practically the same way. Clear cutting or shelter-wood cutting is satisfactory in even-aged stands, depending on whether or not advance growth is present; selection cutting in uneven-aged stands. No slash disposal is necessary. Clearings and thinnings are both desirable where market conditions permit. Yields are about the same as in the oak type.

PINE-HEMLOCK

Where adequate reproduction is already present, either in virgin or second-growth stands, clear cutting will give satisfactory results. Where it is not present, the shelter-wood method should be used. In the second cutting, which should come 5 to 10 years after the first, care should be taken to avoid injury to the young conifers and at the same time to cut back the advance growth of hardwoods. Coniferous slash should be burned in small piles, preferably as the logging proceeds, and when the woods are moist enough to prevent fire from running. Clearings and thinnings are desirable but usually less practicable than in the white pine type.

PINE (PITCH AND SHORTLEAF)

Clear cutting is advisable in moderately open stands where a fair amount of pine reproduction is present. In dense stands with few seedlings a heavy shelter-wood cutting which removes 50 to 70 per cent of the crown canopy will stimulate reproduction, and the remainder of the stand can be removed after the reproduction is well established. Seed trees sometimes give good results and can be used to advantage in connection with both clear cutting and shelter-wood cutting, in order to afford a supply of seed for restocking the area in case the young stand should be destroyed by fire. There should be 5 to 10 windfirm trees per acre with sufficient crown to produce abundant seed. Shortleaf pine should be favored against pitch pine. Where the pine tops can not be used for fuel they should be burned in small piles or lopped and scattered. Thinnings are usually unnecessary because of the absence of hardwood competition. Thinnings in dense stands should be made as early as possible and never later than 40 or 45 years of age.

PINE-OAK

In the pine-oak type clear cutting results in so vigorous a reproduction of oak sprouts that any advance growth of pine that is present is likely to be suppressed. The proportion of pine can be maintained by planting several hundred pine trees in the openings among the stumps after the clear cutting, and then cleaning back the competing hardwoods. Thinnings are desirable where there is a market for the product, and should aim to favor pine.

SCRUB OAK

If fire is kept out of the scrub oak type various other oaks, pitch pine, and in New Jersey shortleaf pine, gradually creep in and replace it. This process can be hastened and the growth of the invading species accelerated by cutting back the scrub oak. Elsewhere conversion of the type to a more valuable one can be affected by burning followed by the planting of shortleaf pine. At least one subsequent clearing is likely to be necessary to insure the establishment of the planted trees.

CONCLUSION

The next step beyond the practice of good silviculture is to handle a forest property so as to obtain a regular income from it. This necessitates a knowledge of the amount of standing timber, of forest capital, and of its rate of growth. On the basis of this knowledge, logging operations can be so planned as to maintain a constant income from the forest capital by cutting during any given year or period of years only the quantity of timber grown during that period.

The production of full timber crops often requires an outlay that could be avoided by letting nature take its course; but this outlay is reasonably sure to be repaid many fold by the increased value of the final product. This is particularly true in the Northeast, where favorable climatic and soil conditions, desirable trees, and excellent markets combine to make timber growing a profitable business.

LIST OF THE TREES AND SHRUBS REFERRED TO IN THIS BULLETIN

COMMON NAME	SCIENTIFIC NAME
Ash, black.	*Fraxinus nigra.*
Ash, white.	*Fraxinus americana.*
Aspen.	*Populus tremuloides.*
Aspen, largetooth.	*Populus grandidentata.*
Basswood.	*Tilia glabra.*
Beech.	*Fagus grandifolia.*
Beech, blue.	*Carpinus caroliniana.*
Birch, gray.	*Betula populifolia.*
Birch, paper.	*Betula papyrifera.*
Birch, river.	*Betula nigra.*
Birch, sweet.	*Betula lenta.*
Birch, yellow.	*Betula lutea.*
Butternut.	*Juglans cinerea.*
Cedar, northern white.	*Thuja occidentalis.*
Cedar, southern white.	*Chamaecyparis thyoides.*
Cherry, black.	*Prunus serotina.*
Cherry, pin (fire).	*Prunus pennsylvanica.*
Chestnut.	*Castanea dentata.*
Dogwood.	*Cornus florida.*
Elm, American.	*Ulmus americana.*
Fir, balsam.	*Abies balsamea.*
Gum, black.	*Nyssa sylvatica.*
Hazelnut.	*Corylus americana* and *C. rostrata.*
Hemlock, eastern.	*Tsuga canadensis.*
Hickory, bigleaf shagbark.	*Hicoria laciniosa.*
Hickory, mockernut.	*Hicoria alba.*
Hickory, pignut.	*Hicoria glabra.*
Hickory, shagbark.	*Hicoria ovata.*
Hophornbeam.	*Ostrya virginiana.*
Larch, European.	*Larix europaea.*
Larch, Japanese.	*Larix leptolepis.*
Magnolia, cucumber.	*Magnolia acuminata.*
Maple, mountain.	*Acer spicatum.*
Maple, red.	*Acer rubrum.*
Maple, silver.	*Acer saccharinum.*
Maple, striped.	*Acer pennsylvanicum.*
Maple, sugar.	*Acer saccharum.*
Oak, bear (scrub).	*Quercus ilicifolia.*
Oak, black.	*Quercus velutina.*
Oak, blackjack.	*Quercus marilandica.*
Oak, bur.	*Quercus macrocarpa.*
Oak, chestnut.	*Quercus montana.*
Oak, pin.	*Quercus palustris.*
Oak, post.	*Quercus stellata.*
Oak, red.	*Quercus borealis maxima.*
Oak, scarlet.	*Quercus coccinea.*
Oak, "scrub" (bear).	*Quercus ilicifolia.*
Oak, swamp white.	*Quercus bicolor.*
Oak, white.	*Quercus alba.*
Pine, northern white.	*Pinus strobus.*
Pine, Norway.	*Pinus resinosa.*
Pine, pitch.	*Pinus rigida.*
Pine, Scotch.	*Pinus sylvestris.*

COMMON NAME	SCIENTIFIC NAME
Pine, shortleaf.	*Pinus echinata.*
Poplar, yellow.	*Liriodendron tulipifera.*
Sassafras.	*Sassafras variifolium.*
Serviceberry.	*Amelanchier canadensis.*
Spruce, black.	*Picea mariana.*
Spruce, Norway.	*Picea abies.*
Spruce, red.	*Picea rubra.*
Spruce, white.	*Picea glauca.*
Sycamore.	*Platanus occidentalis.*
Tamarack.	*Larix laricina.*
Viburnum.	*Viburnum* sp.
Walnut, black.	*Juglans nigra.*
Willow.	*Salix* sp.
Witch-hazel.	*Hamamelis virginiana.*

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THE KILN DRYING OF SOUTHERN YELLOW PINE LUMBER

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THE KILN DRYING OF SOUTHERN YELLOW PINE LUMBER[1]

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INTRODUCTION

IMPROVING THE UTILIZATION OF OUR FOREST CROP

The Forest Products Laboratory has for many years been engaged in studying ways and means of obtaining the best return from our

[1] The Forest Products Laboratory acknowledges the cooperation of the Southern Pine Association; the Lufkin Land & Lumber Co., of Lufkin, Tex.; the Central Coal & Coke Co., of Conroe, Tex.; and the Kaul Lumber Co., of Tuscaloosa, Ala., whose active participation in the survey, the practical tests, and the demonstrations carried out in the course of the investigation were of material assistance. The laboratory is also indebted to a number of other southern yellow pine manufacturers, who assisted in diverse ways during the surveys and the experiments reported in this bulletin. The writer acknowledges especially the work of A. C. Knauss, who as an engineer at the Forest Products Laboratory conducted the survey of 1922 and made the early experiments at commercial plants.

[2] Maintained by the United States Department of Agriculture at Madison, Wis., in cooperation with the University of Wisconsin.

forest land, especially through the reduction of waste in using the forest crop. The fullest utilization of this crop not only requires intelligent felling and logging methods in the forest but also requires that the highest yield be obtained from the log. In lumber manufacture this means the highest possible yield of lumber, both in quality and quantity. The utilization of low-grade lumber is one of the key problems in the practice of forestry; the demand is for high-grade material. If poor seasoning reduces the grade of lumber, then more trees must be cut to supply the demand; hence a needless drain, since poor seasoning is usually preventable.

Improvement in seasoning practice will increase the net forest yield through reduction of waste; it will help to retain the potential value of the crop through reduction of seasoning defects. Further, although the inherent properties of a piece of wood are determined initially by the species and growth conditions of the tree, these properties can be modified through proper seasoning treatment, and lumber can thus be made more suitable for its ultimate use requirements. Hence improvement in seasoning for suitability, in addition to improvement in seasoning to decrease actual waste, will again make for better utilization of our forest crop.

AVAILABLE INFORMATION ON KILN DRYING

A large amount of information on the kiln drying of lumber is available (*1, 3, 4, 5, 6, 7, 8, 9, 10, 11*).[3 4] Some of it, however, is too general in character to meet specific needs fully. The southern yellow pines, like many other species, have certain problems peculiar to themselves, making a definite and detailed treatment of those problems desirable for best results in kiln drying.

Until quite recently it was assumed in the trade that the degrade resulting from the kiln drying of southern yellow pine was very low. However, a survey of seasoning practice and degrade made by the Southern Pine Association in 1921 and a similar survey made by the Forest Products Laboratory in cooperation with the Southern Pine Association in 1922 brought out the fact that the actual drying losses were much greater than had been supposed, and the opportunity for improvement then became obvious. It was estimated in 1922 that the annual loss from kiln-drying degrade suffered by the southern yellow pine industry approached $10,000,000. The practical seasoning experiments that were initiated after the two surveys had been completed demonstrated that the adoption of the best kiln-drying practice for the seasoning of southern yellow pine was technically and economically sound.

SCOPE AND OBJECT OF THE BULLETIN

The purpose of this bulletin is to present briefly the general principles of kiln drying and then to show the application of these principles to the kiln drying of southern yellow pine lumber. Specifi-

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[3] Italic numbers in parentheses refer to "Literature cited," p. 66.

[4] The Kiln Drying Handbook (*5*) presents a full discussion of the general subject of kiln drying. It contains descriptions, more detailed than those offered here, of such matters as the technic of moisture-determination and of moisture-distribution tests, following daily drying rates by means of samples of known initial moisture content, determining humidity in the kiln, and the construction and operation of various kinds of kiln equipment.

cally, it is intended to show (1) how to control drying conditions in the kiln, (2) the proper method of handling stock before and after kiln drying, and (3) how observance of proper kiln operation and handling methods is economically advantageous.

FUNDAMENTAL PRINCIPLES OF KILN DRYING SOUTHERN YELLOW PINE

BEHAVIOR OF MOISTURE IN WOOD

MOISTURE IN THE WOOD

The seasoning of lumber may be considered chiefly as the removal of the excess moisture in the wood, thereby making the material more suited for its ultimate use. In the standing tree the moisture, which is commonly called sap, serves to distribute food and thus assists growth, but after the tree has been cut the moisture is superfluous. In commercial seasoning, however, some moisture is left in the wood, although most of it is removed.

TRANSFUSION OF MOISTURE

Moisture is held in wood in two ways: (1) As free water in the openings or cell cavities and (2) as imbibed water in the cell walls. When drying commences the moisture dries out of the cell cavity first and then dries from the cell wall. All moisture removed, of course, is carried away from the exposed surfaces; the moisture moves from parts of high to parts of low moisture content somewhat as a fluid travels along a wick. The structure of wood results in resistance to the flow of moisture; this resistance varies widely among different species. Southern yellow pine does not offer so much resistance to the movement of moisture as many of the other softwoods do, a point that simplifies its seasoning problem very materially. At the same time the resistance to the passage of moisture has an important bearing on shrinkage, and shrinkage causes most of the difficulty encountered in seasoning, whether it is in pine or in other species.

FIBER-SATURATION POINT AND SHRINKAGE

As green wood dries, the cell cavities become empty first and when they are entirely empty the cell walls start to dry. As long as there is any water in a cell cavity that cell will not shrink, but shrinkage does begin as soon as the water commences to leave the cell walls. The stage when the cell cavity is empty and the cell walls are still saturated is called the "fiber-saturation point." Since drying commences at the surface, the outer part of the wood attempts to shrink first but the more moist inner part resists such shrinkage, although usually without complete success. At this period the surface is in tension, tending to compress the inner part much as a rubber band around a book tends to compress the book. Often such tension becomes severe enough to rupture the surface fibers, the results appearing then as surface checks and as end checks. Sometimes these checks do not penetrate very far into the pieces, so that later, when the interior dries and shrinks, they may close, though they never heal.

MOISTURE GRADIENT

Some shrinkage will develop as soon as drying begins, but it is only surface shrinkage. Should the condition of drying be such that the surface would dry to a very low moisture content [5] soon after the piece entered the kiln, a sharp difference in moisture content would develop between the surface and the parts just below it, on account of the resistance of the wood substance to transfusion of moisture. Such a difference in moisture content, which causes a flow of moisture from the part of high content to that of low, sets up the condition called a moisture gradient. A moisture gradient is most conveniently represented by a curve because it is a change in condition. (Figs. 1 and 2.) A steep moisture gradient practically at the surface brings about two undesirable effects, surface checking and surface set. The term "surface checking" is self-explanatory. Surface set, which will be explained later, causes casehardening, it may cause honeycombing, with or without surface checking, and it contributes to other conditions that ultimately result in degrade.

Obviously, if stock could be dried without setting up a moisture gradient, then shrinkage problems could be reduced to a negligible minimum. Actually, however, a moisture gradient is necessary to create transfusion and drying can not take place without transfusion, although on the other hand the gradient must not be too steep because of the bad results that follow excessive steepness. The moisture content at the surface is determined by the drying conditions to which the surface is subjected, these conditions being the temperature, the humidity, and the circulation of the surrounding atmosphere. It is necessary to consider these factors in some detail in order to understand more fully the part each one plays in the principles involved in seasoning.

TEMPERATURE

Temperature is an index of the heat condition of a substance. Degrees of temperature represent intensities of heat. Temperature and heat are so closely associated that a discussion of either practically always involves the other.

CONSUMPTION OF HEAT

Heat is required to evaporate the moisture in lumber as its comes to the surface of the piece. Evaporation consumes heat, and continuous evaporation consequently requires a continuous supply of heat. The fact that evaporation consumes heat can be readily understood by any one who has passed around a pile of lumber in an air-seasoning yard on a warm, sunny day. The air on the side against which the wind is blowing will be relatively warm, while on the opposite side and below the pile it will be several degrees cooler. Furthermore, if the lumber has been freshly stacked and is full of water the cooling effect will be more noticeable than that around old piles of nearly dry lumber, because of the greater amount of evapora-

[5] Moisture content may be defined as the ratio of the weight of moisture present in wood to the weight of the dry wood substance; it is always expressed in per cent. Methods of determining moisture content will be described later (p. 46).

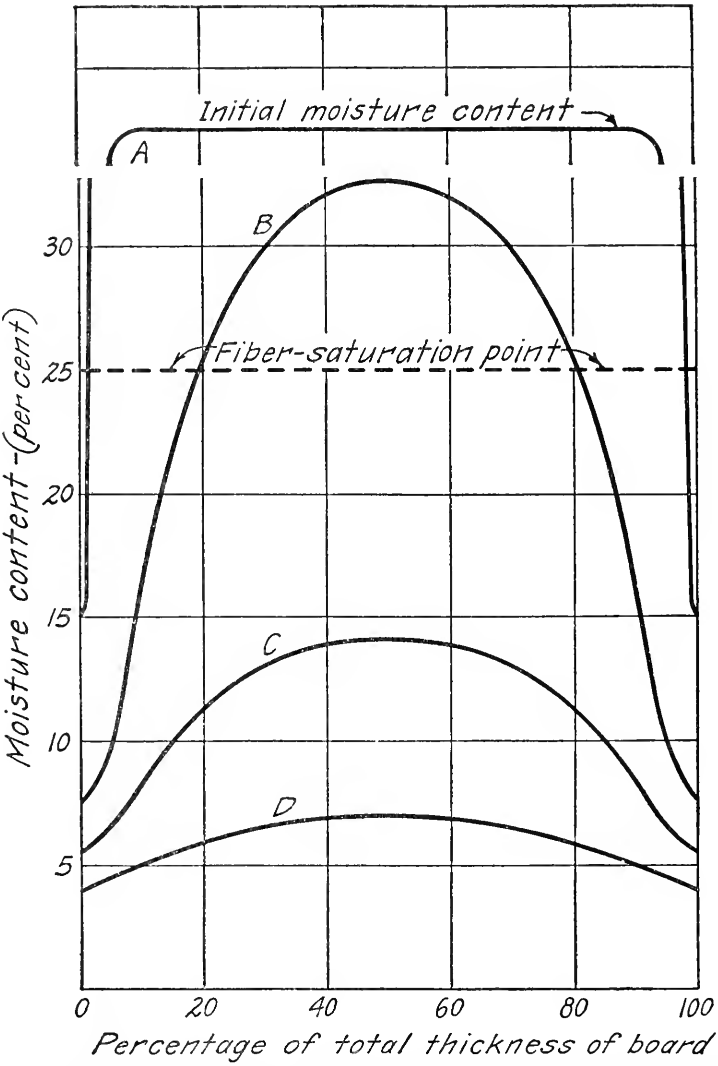

FIGURE 1.—A graphical illustration of typical moisture gradients, across the thickness of a board in the entering-air portion of the pile, at four stages in the drying of No. 1 Common and Better southern yellow pine. The horizontal line at the bottom of the figure represents a line running through the board from face to back, perpendicular to the face, at any representative part of the board (the moisture gradients near the edges and the ends of a board differ somewhat from the typical gradient). The point marked "0" represents any typical point in the face of the board. Hence distances from the vertical line at the left of the figure, which is called the vertical axis, represent distances in from the face of the board. Consequently, each point on one of the curves represents the moisture content (see the scale at the left) of the wood at the spot in any cross section of the board that is indicated by the distance of the point from the vertical axis. Each curve, therefore, shows the change in moisture content along a straight path squarely through the board. Curve A is intended to represent the moisture gradient at the end of the 5-hour period of Schedule 107 (p. 43), shortly after drying has commenced. The moisture content in the center of the board then is still very high, but that at the surface has practically reached equilibrium with the surrounding atmosphere. The value of the moisture content at the surface—the boundary condition—is fixed definitely by the temperature of the surrounding atmosphere, the humidity, and the rate of circulation, while the moisture within the board may differ more or less from the values shown because of variation both in the initial moisture content and in the rate of drying (which is affected by the structure of the wood), and because of the presence of heartwood, sapwood, and pitch. Curve B illustrates similarly the average moisture gradient in a board after 35 hours in the kiln, curve C that after 59 hours, and curve D that at the end of the run

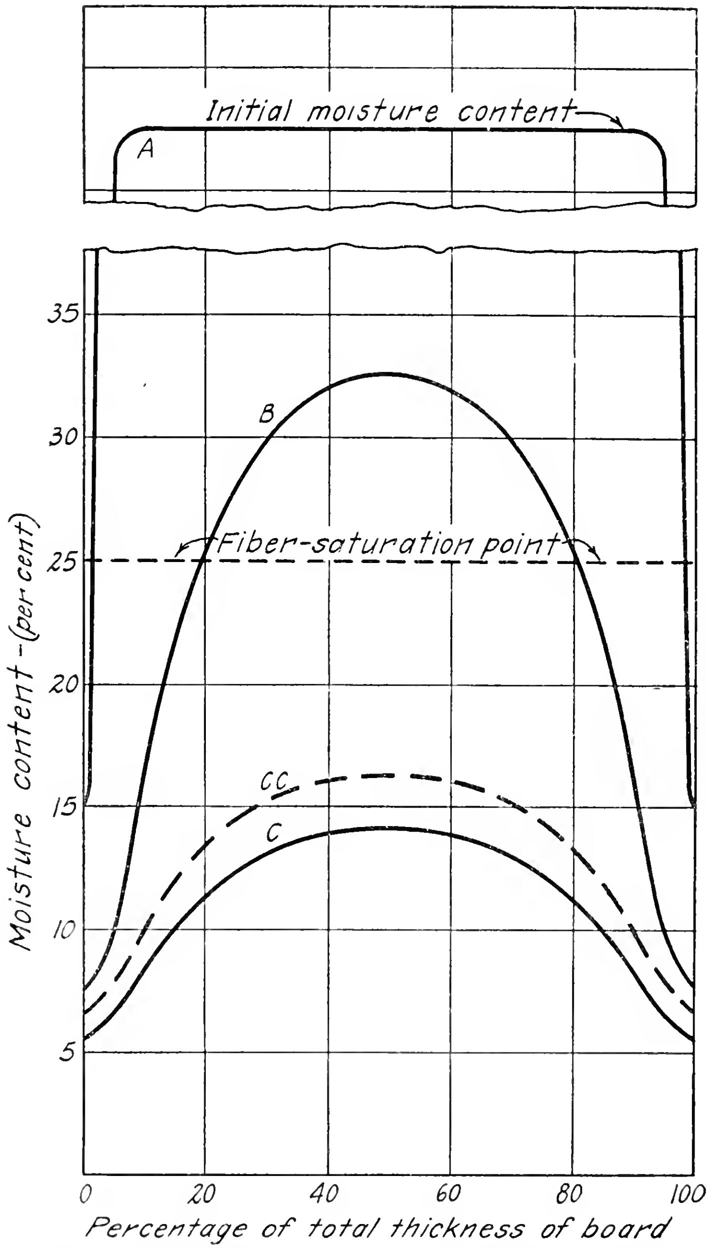

FIGURE 2.—A graphical illustration of moisture gradients, across the thickness of a board in the entering-air portion of the pile, at four stages in the drying of No. 2 Common and lower grades of southern yellow pine. Curve A is intended to represent the moisture gradient at the end of the 5-hour period of Schedule 108 (p. 44), shortly after drying has commenced. Curve B illustrates similarly the average moisture gradient in a board after 35 hours in the kiln, and curve C that for ordinary No. 2 Common stock at the end of the run. Curve CC shows the probable final conditions when the schedule has been modified, giving a higher final moisture content, for stock containing large knots. For further explanation see Figure 1

tion from the green wood. Hot, dry air passing through a truck load of wet lumber in a kiln will emerge several degrees cooler than when it entered.

The heat, measured in British thermal units, needed to separate water from wood by evaporation increases as the wood dries below the fiber-saturation point. Such increase is small, however, when compared with the heat necessary to evaporate free water. For example, under usual conditions about 1,000 British thermal units is required to evaporate 1 pound of free water and only about 135 British thermal units additional is required when the water is absorbed by wood substance.

THE EFFECTS OF HEAT AT A HIGH TEMPERATURE

The transfusion of moisture through wood is stimulated by heat. Since in commercial work the rate of drying is limited by the rate of transfusion and heat stimulates transfusion, it follows that the higher the temperature the faster the drying, other conditions remaining constant.

The moisture-holding capacity of air is much greater at high temperatures than at low. Because of its increased capacity a given amount of dry air at a high temperature will carry away more moisture than at a low one.

Heat is used to produce circulation of the air in a dry kiln. In all kilns not equipped with mechanical means for moving the air, circulation is a result of differences in temperature, heat causing the air to rise and the cooling resulting from evaporation and radiation losses causing it to fall.

In addition to the foregoing there are several other ways in which heat plays an important part in drying. At the temperatures common in kiln-drying southern yellow pine, for instance, heat will kill the fungous organisms that cause mold, stain, and decay. Further, heat in combination with moisture makes wood somewhat more plastic than it is when cold or dry, a fact that may be used to reduce stresses caused by uneven shrinkage. Besides these things, heat affects both the color and the strength of wood and accordingly good practice requires that kiln temperatures be kept below the temperature that might cause appreciable weakening or discoloration. This bulletin, however, is not primarily concerned with any reduction in strength properties that may result from drying under the schedules presented herein; these schedules are milder than those that have been customary for southern yellow pine lumber in the past.

HUMIDITY

Establishing high temperatures in order to hasten drying and then maintaining relative humidities [6] that reduce the rate of evaporation may seem inconsistent. As stated earlier, however, the factor con-

[6] The term "relative humidity" refers to the ratio of moisture actually present in the air to the maximum amount the air can hold at the same temperature; it is expressed in per cent. The amount of moisture the air can hold varies with its temperature. At any given temperature the greatest amount of water vapor that air can hold is fixed, but any less amount than this maximum may occur. Increasing the temperature of air increases its capacity for moisture and thus, with the same amount of water vapor present, reduces the relative humidity. Lowering the temperature decreases its moisture-carrying capacity and therefore increases the relative humidity.

trolling the rapidity of seasoning is transfusion rather than surface drying. Although rapid transfusion requires a high temperature, at the same time good drying requires that the moisture gradient shall not be too steep.

EQUILIBRIUM MOISTURE CONTENT

Wood is a hygroscopic material; that is, it has the property of taking up or of giving off moisture according to the conditions to which it is subjected. Air (or more properly the space occupied by air) has the same property. If wet wood is placed in a dry atmosphere the air will take moisture from the wood and if dry wood is subjected to damp air it will take up moisture from the air. At any given temperature there is a definite relation, called

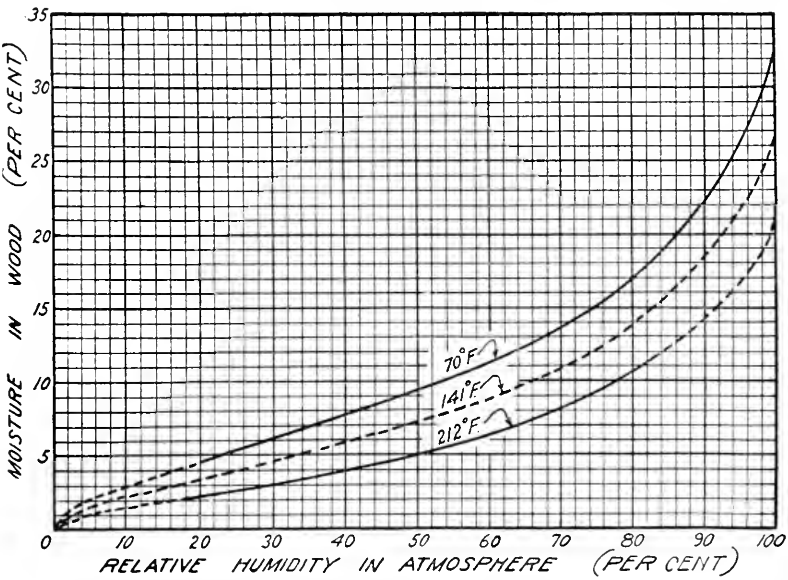

FIGURE 3.—Relation of the equilibrium moisture content of wood to the relative humidity of the surrounding atmosphere, at three temperatures

the point of equilibrium, between the moisture content of wood and the relative humidity of the atmosphere when the wood and the air have been in contact long enough to reach a constant condition. An equilibrium moisture-content curve, which has been worked out with a fair degree of accuracy, is illustrated in Figure 3. This curve shows that the higher the temperature the lower the equilibrium point, at a constant relative humidity. For instance, at 75 per cent relative humidity and an ordinary atmospheric temperature of 70° F. the equilibrium moisture content is about 15 per cent, which in most localities corresponds quite closely to thoroughly air-dried stock, while at 212° and 75 per cent relative humidity the moisture content is about 9½ per cent. Knowing the equilibrium moisture content for various temperatures and relative humidities, it is possible to control the surface moisture content by controlling temperature and humidity, thereby controlling the moisture gradient. This is the basis of proper drying schedules.

CIRCULATION

A constant movement of the surrounding atmosphere is necessary to carry heat to drying lumber to replace that consumed by evaporation and to carry away the moisture evaporated from the lumber. Southern yellow pine dries with comparative rapidity and consequently a large amount of heat is necessary to maintain the highest permissible rate of evaporation. This in turn means that a rather brisk movement of air is also required; otherwise evaporation does not take place uniformly throughout the pile. If air enters a pile of green lumber at 175° F. and 70 per cent relative humidity and is cooled by evaporation to 160° it will become saturated. This condition is frequently seen at the green end of a progressive kiln for several hours after it has received a fresh load of southern yellow pine. The air entering the top of the load and progressing downward through the pile becomes saturated in the first few feet of travel and then the lower part of the load, not having received enough heat to warm it, cools the saturated air still further and thus condenses some of the moisture; the condensation may be seen dripping from the bottom of the load. With a more brisk movement the air could travel through the pile so fast that it would not become saturated and would therefore quickly begin to dry stock not only where it enters but also throughout the pile, including the point where it leaves.

EFFECT OF SHRINKAGE AND OF SWELLING

It has already been pointed out that shrinkage forms the basis of practically all drying difficulties. With results of shrinkage eliminated, drying would present no problems of consequence; actually, however, the whole system of seasoning revolves around this important factor. Although shrinkage can not be prevented in drying nor swelling in reabsorption of moisture, an understanding of these phenomena will make it easier to understand how the results of shrinkage and swelling may be minimized. It may be well to repeat that shrinkage begins when the free water has been evaporated from a cell and the moisture contained in the cell wall begins to dry out (p. 3). From this point on to an oven-dry condition the shrinkage ordinarily is almost directly proportional to the amount of moisture lost. Conversely, when wood absorbs moisture the expansion normally is proportional to the amount of moisture gained, up to the fiber-saturation point. The fiber-saturation point in southern yellow pine is at about 25 per cent moisture content, while the moisture content of green stock may be considerably over 100 per cent of the oven-dry weight. There is a slight shrinkage from the very beginning of the drying period because the outer fibers dry below the fiber-saturation point long before the bulk of the piece reaches that point.

RELATION OF SHRINKAGE AND DIRECTION OF GRAIN

The physical structure of wood is such that shrinkage is unequal in directions that differ with respect to the grain. In normal, straight-grained southern yellow pine there is practically no shrinkage along the grain, but across the grain radially the total shrinkage averages about 5 per cent and across the grain tangentially about 7 per cent.

The shrinkage in longleaf[7] pine lumber is slightly greater than that in shortleaf and loblolly, and there also is a slight difference in this respect between heartwood and sapwood of the same species. The average shrinkage of longleaf pine first air dried at about 70° F. and finally oven dried in order to obtain complete shrinkage is shown in Figure 4, and that for shortleaf and loblolly pine in Figure 5; the shrinkages of loblolly and of shortleaf are substantially the same. A few individual test pieces varied as much as 40 per cent above or below the values given, but 67 per cent of the stock ordinarily cut, if dried to 12.5 per cent moisture content, will fall within 1 per cent of the shrinkage indicated for its species for that value of moisture content. Above 12.5 per cent the limits fall closer and closer to the average value until they practically coincide at the upper range of moisture content given.

Normal shrinkage in a board is practically proportional to the amount of moisture the board has lost below the fiber-saturation point (p. 42). For instance, referring to the curve of radial shrinkage in longleaf heartwood (fig. 4), a heart board dried to 10 per cent moisture content will shrink radially only 3 per cent from its green dimension, that is, about three-fifths of the average shrinkage for zero moisture content. Similarly, at the other extreme, a piece of longleaf sapwood dried to 10 per cent moisture content will shrink tangentially approximately 4.5 per cent of its green dimension, that is, also about three-fifths of the average total shrinkage. Since few pieces of lumber are either truly radially grained or truly tangentially grained, however, in commercial work shrinkage may be considered proportional to the amount of moisture lost below the fiber-saturation point, and the amount of shrinkage may then be estimated roughly on this basis. For example, the shrinkage of a piece at 10 per cent moisture content may be taken as $\frac{25-10}{25}=15/25$ or three-fifths of its average total shrinkage, which is about 6 per cent across the grain and about 12 per cent in volume for southern yellow pine.

Certain kinds of abnormal wood, that is, wood with parts of abnormal growth or with diagonal or crooked grain, will shrink lengthwise of the board. This is usually because the shrinkage across the grain effects the length of the board when the grain is diagonal or crooked. For instance, the irregular grain around knots will cause localized longitudinal shrinkage. "Compression wood" is a name given to a growth condition found at times in many softwoods, including southern yellow pine; in its most common form the pith of the tree is off center, with wide, heavy, annual growth rings on one side of the pith and narrow rings on the other. Boards cut so as to contain some of the heavy rings, the actual compression wood, will shrink longitudinally, thus forming an exception to the general rule for lengthwise shrinkage. Crook is almost always associated with

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[7] The names of species appearing in this bulletin are the standard common names given in the Check List of the Forest Trees of the United States, Their Names and Ranges (2).

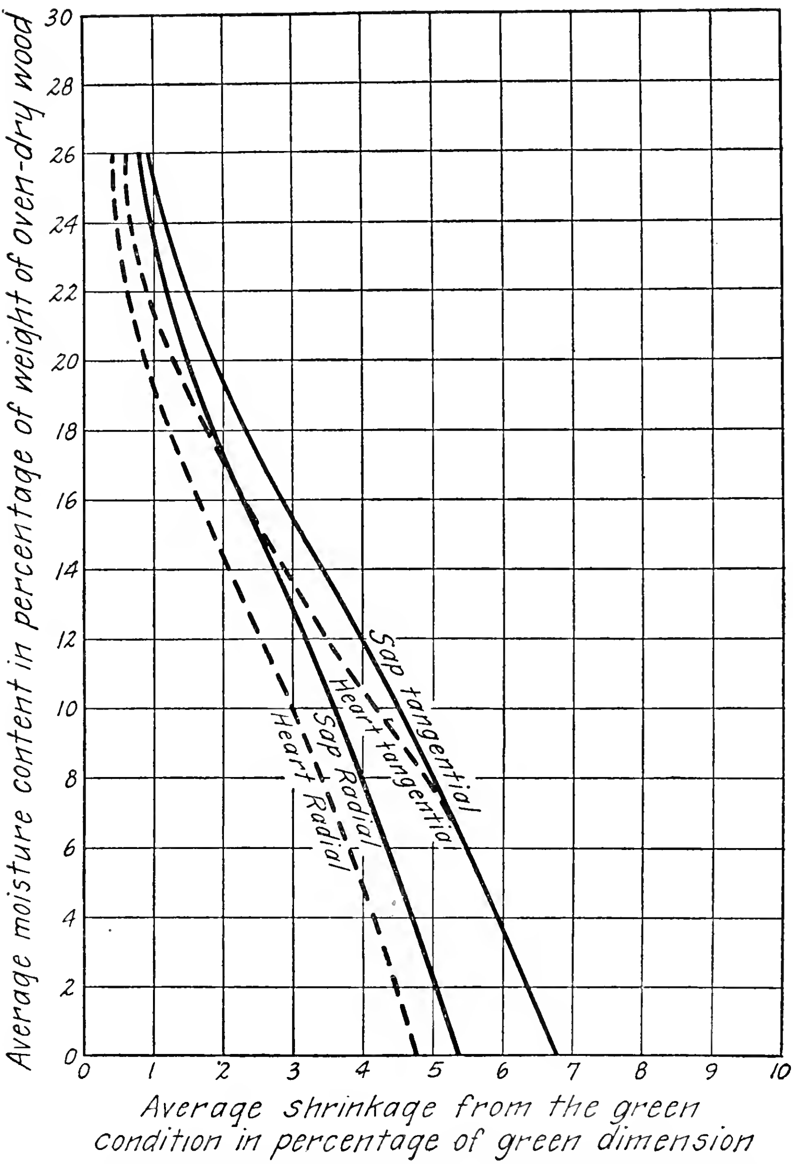

FIGURE 5.—Average shrinkage, with decrease in moisture content, of 1 by 6 inch green commercial longleaf pine boards dried under conditions closely equivalent to ordinary summer weather in the southern pine region, except that the final conditions ultimately brought the moisture content to zero

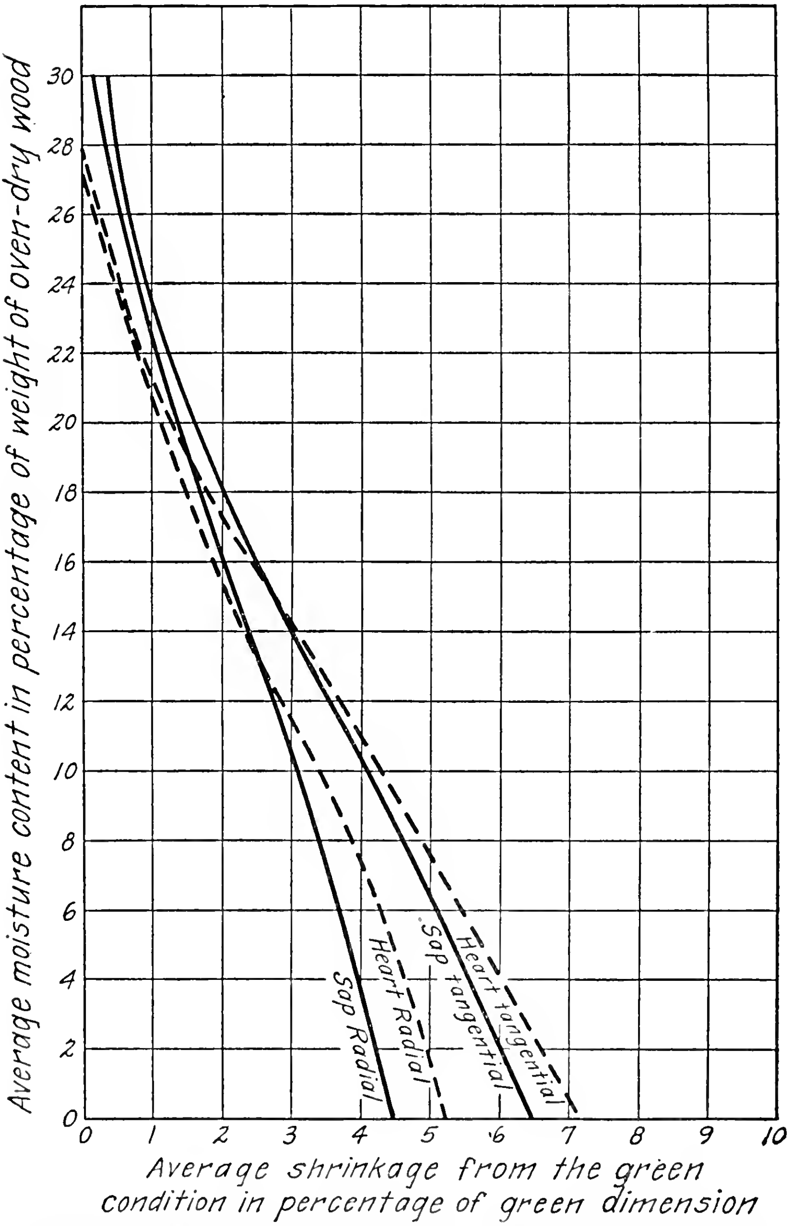

FIGURE 5.—Average shrinkage, with decrease in moisture content, of 1 by 6 inch green commercial shortleaf and loblolly pine boards dried under conditions closely equivalent to ordinary summer weather in the southern pine region, except that the final conditions ultimately brought the moisture content to zero

compression wood; when a board is crooked because of compression wood, one of its edges contains more compression wood than the other. (Pl. 1.)

The term "compression wood" should not be confused with compression stress, which will be discussed in connection with checks and casehardening.

CHECKS

Surface and end checks in lumber are a result of two shrinkage factors, one of which is the difference in shrinkage between the surface and the interior of the piece and the other the difference between radial and tangential shrinkage. They occur during the period when the surface is in tension and the center in compression. (See "Casehardening," p. 14.) Checks should not be confused with planer splits, which are caused by an entirely different condition in the lumber.

HONEYCOMBING

Honeycombing is a rupture in the interior of the piece along the grain of the fibers, a condition sometimes referred to as internal checking. It occurs during the final period of drying, when the surface is in compression and the interior in tension. Honeycombing is very uncommon in 4/4-inch and 6/4-inch southern yellow pine, but is sometimes found in stock over six quarter inches in thickness.

KNOTS

Loose, checked, and broken knots, which are responsible for a high percentage of the degrade in the common grades of southern yellow pine lumber, are caused by some combination of the following three laws of shrinkage: (1) The exposed surface of the knot, which is end grain, dries more rapidly than the portion of the board surrounding it, and consequently shrinks away from the board while the board is too wet to shrink. (2) Wood shrinks very little along the grain but considerably across the grain. As a result the knot shrinks in all directions on the face of the board, but not much in thickness, whereas the board shrinks in width and in thickness but not much in length. After drying, although the knot is thicker than the board it tends to occupy a smaller cross-sectional area than that of the space for it in the board, and therefore it usually has either checked or become loose. Incased and dead knots are most likely to become loose and fall out. Live or intergrown knots are least subject to damage, and that which occurs is usually checking or breaking in the planer. Knots that might otherwise be held by growth tissue or friction are likely to be loosened in the planer because of both their hardness and the abuse they receive from the planer knives. (3) Heavy or dense wood shrinks more than light wood and, since knots are more dense than the surrounding stock, their percentage of total shrinkage is greater. White and red knots are frequently so intergrown with the surrounding stock that the bond thus formed is stronger than the knots, causing them to check or split in drying.

The size of the knot is also an important factor in knot defects, small knots frequently remaining tight although few large knots go through a planer undamaged. The direction of the grain in knots and their structure make them more brittle than the surrounding wood and hence more liable to breakage in the planer. Brittleness in knots increases as the moisture content decreases and because of this more breakage will occur in knots in the usual run of kiln-dried stock, which has a relatively low moisture content, than in air-dried stock. The proper method of kiln drying to prevent or at least to reduce the liability of damage to knots will be discussed later (p. 42).

CASEHARDENING

Casehardening is the term commonly used to describe a condition in dry lumber that, for instance, causes it to cup when the stock is resawed; the condition is a result of unequal stresses that develop because of unequal shrinkage in the cross section of a board as it dries. Immediately after drying starts the surface of the board dries below the fiber-saturation point and then attempts to shrink. At the same time the wood just beneath the surface is still above the fiber-saturation point and it naturally opposes the surface shrinkage. In this stage the surface fibers squeeze the core, thereby setting up compression stresses in it and tension in themselves. As the drying progresses the outer fibers, because of the restraint of the adjoining wet inner fibers, shrink less than they would if they were free and as a result they become set. With still further progress in drying, successive layers of fibers beneath the surface dry below the fiber-saturation point and each in turn is restrained, first by the inner portion of the piece and ultimately, when the core has dried, by the outer portion. While the surface is drying it is in tension and the center of the piece is in compression; during the later stage of drying the center is in tension and the surface in compression. Since the core is the last to try to shrink it continues to exert an internal pull after the entire piece is dry. When stock is in this condition, with the surface in compression and the core in tension, it is casehardened; if resawed, it would cup at once, even though the moisture content between the surface and the center were uniform.

When a combination of unbalanced tension and compression stresses occurs in opposite faces of a piece of lumber it causes cupping unless the stresses are either counteracted by restraint of the piece or are relieved. Lumber that has more moisture in the center than in the outer portion will always cup more or less after resawing. (Pl. 2.) Such unequal moisture distribution in casehardened stock still further complicates the cupping, because of the shrinkage that results from the equalization of moisture throughout the piece after resawing.

Casehardening is most severe in unrelieved lumber that has had a steep moisture gradient; such a gradient occurs in the stock in kilns where the drying conditions are very severe. Casehardening in air-dried southern yellow pine is almost unknown, and it can be minimized in dry kilns by the use of proper drying schedules.

CHARACTERISTICS OF SOUTHERN YELLOW PINE THAT AFFECT KILN DRYING

Some kinds of southern yellow pine lumber react differently from others during the seasoning process, and accordingly the kiln operator should understand thoroughly both the characteristic differences among the species and those resulting from various growth conditions. Proper consideration of these differences will reduce drying hazards and will speed up the drying process. Stock cut from dense stands will have fewer knots, and less of the seasoning difficulty they cause, than that cut from open stands. Lumber cut from small trees will cup and twist more than stock cut from trees of large diameter. Dense-growth, heavy stock seasons more slowly than lighter stock and is more inclined to warp and check, because dense wood shrinks more than light wood. Hard, heavy, wide-ringed second-growth longleaf pine also contains more moisture than narrow-ringed virgin-growth stock. The same is true of wide-ringed oldfield [8] pine, but it is often less dense than virgin growth. Obviously a larger quantity of moisture to be evaporated adds time to the seasoning process. Second-growth stock will usually contain more sapwood than will virgin or mature-growth stock, and green sapwood always contains more moisture than heartwood, oftentimes more than twice as much. Heartwood of both longleaf and shortleaf pine will contain moisture ranging from 25 to 50 per cent of the weight of the wood, while sapwood contains from 70 to 130 per cent in longleaf and up to 180 per cent in shortleaf. Red heart,[9] which is very common in some localities, usually reduces the moisture content to less than 25 per cent and, therefore, lumber affected with red heart can be dried more rapidly than sound lumber.

Pitch acts as a retardent to moisture transfusion and consequently stock that is heavy with pitch may require twice as long to season as clear stock. It frequently happens that a heavy pitch streak will extend along one face of a board while the other face will be normal, clear stock, a condition that results in unequal drying, usually followed eventually by warping. Sometimes logs that have been lying in the woods for a long time are brought into the mill; the sapwood may be blue stained and the lumber smells sour when the log is cut up. The sapwood from such logs and also that from deadheads dries much more slowly than the sapwood from fresh logs. The moisture content of several sour longleaf pine boards, after four days in a kiln, ranged from 45 to 55 per cent,[10] while the other stock in the same truck load averaged about 7 per cent.

SEASONING TO SUIT MARKETS

The seasoning problem of each southern pine manufacturer is affected by the market in which his stock is sold. On the other hand, the standard of seasoning followed may be the deciding factor in determining the market, low standards limiting it and high standards extending it to include special-purpose material and even premium prices for yard stock. The market for the mill output is influenced by such factors as the following: Species of pine, grades

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[8] "Oldfield pine," as used in the southern lumber regions, designates a growth condition of southern yellow pine and not a species. It is customarily applied to the type of shortleaf and of loblolly pine that has grown in abandoned clearings and consequently has certain ring-growth and knot characteristics that differentiate it, in the mill-man's identification, from all forest-grown trees, either virgin growth or second growth.

[9] Red heart is a stage of incipient decay characterized by a reddish color in the heartwood. "Firm red heart" is the term used to describe the defect in stock where the disintegration processes have not proceeded far enough to affect the hardness of the wood perceptibly. Red heart may occur either in a part or in substantially all of a board.

[10] See footnote 5 on p. 4.

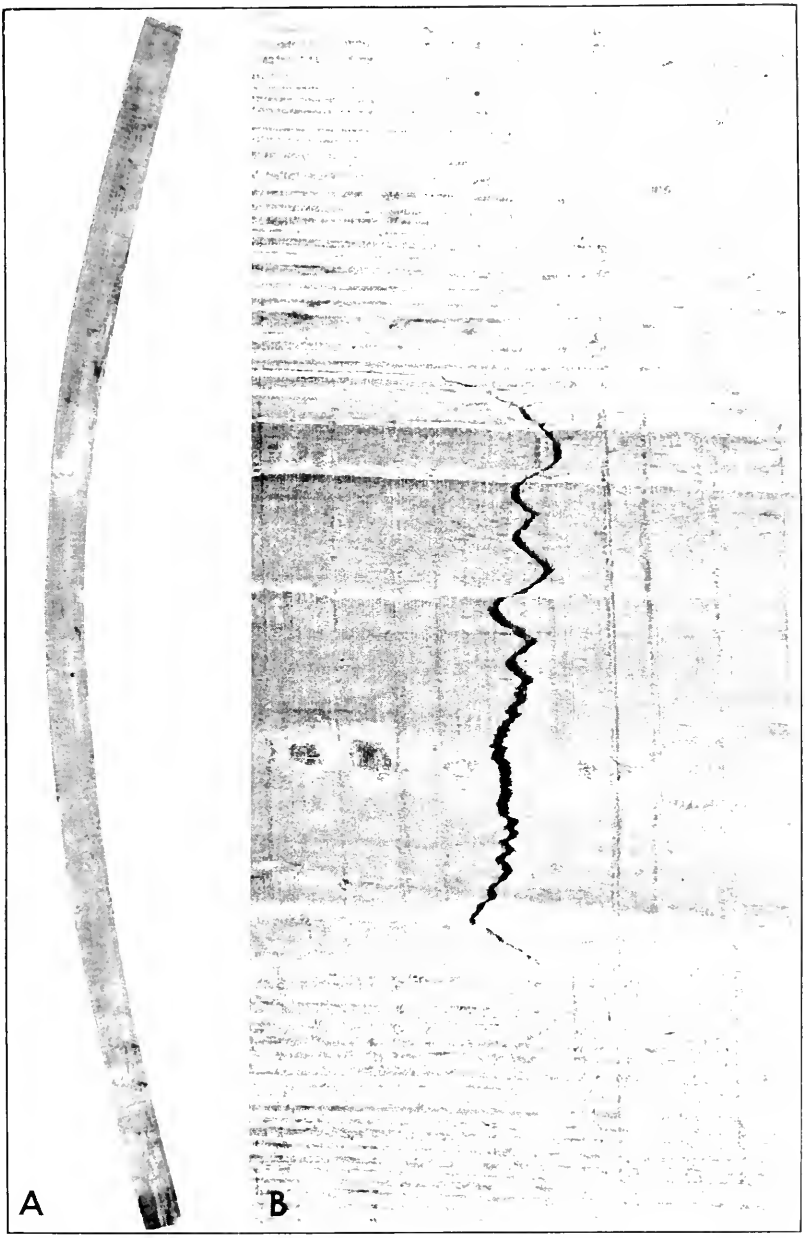
of lumber manufactured, quality of product, price, sales organization, type and size and location of mill, method of transportation, and location of market. In one way or another each of these factors has more or less bearing on the method and the degree of seasoning. Actually, for domestic markets, it is the ultimate use or use requirements that should establish the degree and the standard of seasoning. Lumber grades and their prices practically establish the purposes for which stock will be used; hence, for all ordinary service, seasoning standards may be based on such grades. Building construction absorbs the major portion of the southern yellow pine manufactured. In such construction the upper grades of lumber, No. 1 Common and Better, are required for interior finish, exterior finish, flooring, and other planing-mill products, all of which are used where shrinkage and swelling are objectionable and consequently well-seasoned stock is necessary. The lower grades of lumber are used in rough construction work like side wall and roof sheathing, subfloors, and concrete forms, in which some shrinkage can be accepted without materially affecting the appearance of the finished structure. In such uses the standard of seasoning required is not so high as it is for the upper grades. Studs, joists, and small timbers are often air dried, not kiln dried, and larger timbers are often shipped without any seasoning. Manufacturers of railway cars, automobile bodies, furniture, refrigerators, and other special products usually specify the moisture content that is acceptable to them for the items and grades they purchase.

Quite apart from the question of use requirements, the lumber manufacturer gains several advantages if his stock is properly seasoned. Since rail-transportation charges for a given commodity and length of haul are based on weight, lumber of low-moisture content naturally enjoys a lower shipping charge per thousand board feet than the heavier lumber of higher moisture content. In addition, most southern yellow pine lumber is used in finished sizes, and the manufacturer finds that unless the stock is reasonably dry it does not machine properly. Further, stock is far less likely to develop blue stain if it is kiln dried than if it is not, and unstained stock has a decided sales advantage over stained.

COMPARATIVE MERITS OF AIR DRYING AND OF KILN DRYING

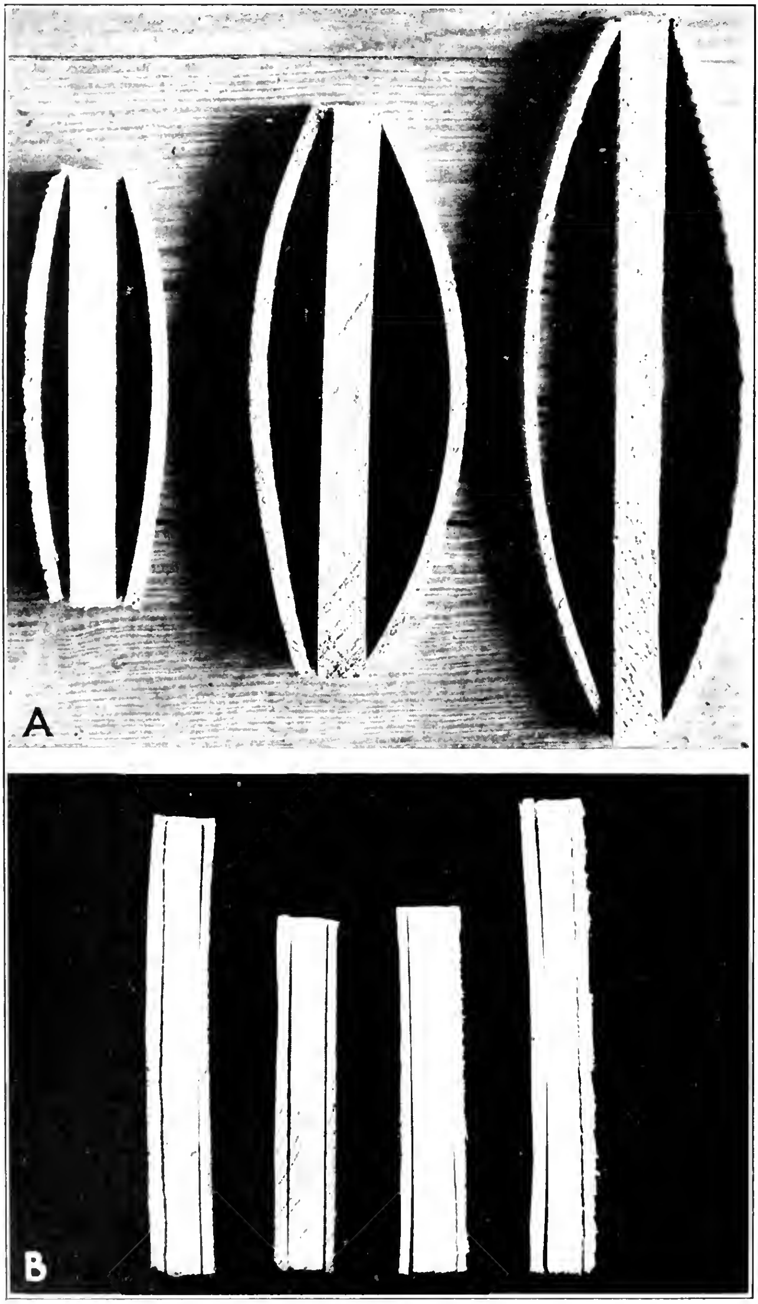
The seasoning of southern yellow pine at the sawmill may be accomplished by air drying or by kiln drying or by both. Air drying is the simpler of the two. For air drying the green lumber is merely open piled in a yard equipped with proper foundations; the stock then requires a minimum of attention during the drying process. The construction of buildings is avoided and the size of the yard can easily be changed to accommodate the cut of the mill. Kiln drying is more complicated, involving kiln buildings, tracks, stacking equipment, an adequate supply of steam, and suitable personnel.

Air seasoning, however, is slow and the stock must remain in the yard for months before it is ready for shipment. Thus the yard grows to an accumulation of several months' output of the mill and, further, it is necessary to carry a complete line of dried stock if



M—11470—F

A.—Crook in 1 by 4 inch kiln-dried southern yellow pine, caused by the longitudinal shrinkage of compression wood during drying. B.—A typical tension failure in southern yellow pine caused by the longitudinal shrinkage of compression wood during seasoning



M—11471—F

A. The cupping that is usual when casehardened southern yellow pine lumber is resawed before the internal stresses have been relieved. B. Sections of southern yellow pine lumber resawed after casehardening stresses have been removed by means of a conditioning treatment in the kiln. The internal stresses will also die out gradually during storage of casehardened lumber in the rough dry shed, but several months must elapse before the results of severe casehardening will entirely disappear under such treatment orders are to be filled promptly. Even then the filling of orders may occasionally be delayed somewhat by unfavorable weather, since in addition to the general slowing down of the seasoning process during cold weather, with the resultant possibility of delay at some future time, is the immediate delay sure to come from rain; stock should not be taken from the pile for some days after a heavy rain.

Kiln drying reduces to a few days the amount of time required for seasoning, and it thus is possible to ship finished lumber within a week or so from the time the log is cut, regardless of the season of the year and regardless of rainy weather. Special orders can be accepted for quick delivery even if no stock of the desired items is on hand.

UPPER-GRADE STOCK

In the upper grades the lower moisture content possible with kiln drying is a particular advantage of that method of drying, inasmuch as such stock does not become dry enough in yard seasoning for the use to which it will be put. After kiln drying, moreover, it can be manufactured at the mill into flooring, finish, and special items, thus materially increasing the market price over what would be possible in the same grades air dried.

BLUE STAIN

Kiln drying also makes it easy to avoid blue stain, which frequently develops in air drying, especially during hot and humid weather. Such stain reduces the value of upper-grade stock and makes it more difficult to market the lower grades. Chemical treatment of green lumber before air drying—such treatment, for instance, as dipping in a solution of bicarbonate of soda—may be efficacious and under certain conditions is satisfactory. Stock that is soda dipped is not desired in some markets, however, and for certain uses is not desired in any market. Proper kiln drying, on the contrary, prevents blue stain more certainly than any other method now known, and at the same time leaves the stock universally acceptable.

LOSSES CAUSED BY FORCING KILNS

The benefits of kiln drying have been so marked that an immense dry-kiln capacity has been put into operation at southern pine sawmills, and in spite of this capacity the demand from the consumer has been for an increasing percentage of kiln-dried lumber. This demand has led to the operation of dry kilns for their maximum production, instead of for their best production, and consequently severe drying conditions have been maintained. Because of these conditions drying defects are common and frequently the resulting degrade is quite heavy. Along with the general advance in the value of southern yellow pine the price difference between grades has also increased, and accordingly any drop in grade caused by drying defects results in a serious loss in value.

SURVEY OF KILN-DRYING PRACTICE

1921 SURVEY

The necessity for efficient kiln drying became particularly evident as a result of a preliminary survey made by the Southern Pine Association in 1921 to determine the current seasoning practice at association mills. In this survey degrade tests were made at 10 mills on both air-dried and kiln-dried stock. It was found that, when kiln-dried stock was manufactured into finished lumber, nearly a third dropped below the grade into which the stock originally had been cut. B and Better lumber averaged 34.5 per cent degrade, No. 1 Common 30.5 per cent, and No. 2 Common 22.5 per cent. Such drops in grade of course meant a serious loss in the value of the lumber, and while it was not expected that all of the degrade could be eliminated by improved kiln drying it was felt that a substantial reduction might be effected if the exact causes of degrade could be determined. The determination required more information about the conditions under which the lumber was being dried than was then available.

1922 SURVEY

The Forest Products Laboratory arranged in 1922 to cooperate with the Southern Pine Association in studying the problems peculiar to the seasoning of pine. The study, which was intended to bring out the cause and the extent of the kiln degrade as well as other factors that might have a bearing on the method of attacking the problem, began with a survey more detailed than that of the previous year. Fourteen representative mills, widely scattered throughout the longleaf and the shortleaf districts, were visited; all these mills had a daily cut of 100,000 board feet or more and were kiln drying a part or all of this cut, and all maintained planing mills.

The conditions found during the survey and in some of the subsequent experiments mentioned herein represent the conditions at the time of observation; at that time they were typical of most of the mills throughout the southern pine area. A number of the southern pine mills have both modified their kilns and otherwise improved their seasoning practice materially since then, but at many of the others the conditions are still about the same as those that existed in 1922.

EXTENT OF KILN-DRYING PRACTICE

The seasoning practice at the larger southern mills was not uniform. Some plants kiln dried only B and Better stock, some included No. 1 Common, and others part of the No. 2 Common. A few mills kiln dried their entire cut of lumber. The mill operators considered kiln drying of the upper grades profitable because it enabled them to manufacture the better lumber into finished sizes or special items. Some, however, were not convinced that it was profitable or even practical to kiln dry the common grades. Such lumber, being used for less exacting purposes than the upper grades, does not require seasoning to so low a moisture content. Kiln drying of the common grades had often led to a severe loss from degrade and consequently such stock was usually air dried, with a smaller resulting degrade. Practically all kiln drying of pine at the southern mills is on stock green from the saw. Lumber that is air dried, wholly or in part, is seldom put through their kilns before shipment.

DRYING CONDITIONS IN THE KILNS

All of the mills visited in the course of the survey were using natural-circulation progressive kilns. High-pressure steam, usually at about 100 pounds gauge pressure and direct from the boilers, was used for heating. The boilers were operated continuously, except at some plants where the steam was shut off over Sundays and holidays.

TEMPERATURE

The operation of the kilns commonly consisted only of such attention as that required for loading and unloading, which left the kilns to themselves at all other times. Under such operation the kiln temperatures and humidities were continually changing as the drying progressed. Rapid evaporation from the fresh lumber kept the green or charging end at a lower temperature than the discharge end, the two temperatures ranging from 150° to 180° F. in some kilns and from 180° to 230° in others. The dry-end temperatures were regularly about 20° to 40° higher than those at the green end. Sometimes when the trucks were not removed from the kilns as soon as their loads had become dry temperatures in excess of 250° were observed. Few operators attempted even to determine the kiln temperatures.

HUMIDITY

The kiln humidity fluctuated with the temperature and with the amount of moisture being evaporated from the lumber. The highest relative humidities were of course found at the green end; they ranged, a few hours after loading, from 60 per cent in kilns with tight walls and doors to 30 per cent in leaky kilns. In a few instances relative humidities at the green end below 20 per cent were also noted. At the dry end the relative humidities were always comparatively low, seldom exceeding 30 per cent, often below 20, and sometimes less than 10 per cent. The source of humidity in practically all kilns was limited to evaporation from the lumber; in only a few instances were steam sprays used for that purpose. The evaporated moisture, escaping through ventilators and chimney cracks and crevices in doors and walls, left the humidity in the kiln a natural balance between the rate at which the moisture evaporated from the wood and its rate of escape from the kiln. In no case observed was automatic humidity-control apparatus installed.

CIRCULATION

The air movement, as with all natural-circulation kilns, was dependent upon a combination of conditions, such as the design and distribution of the heating coils, temperature range, relative humidity, and the method of piling. Since the operators did not thoroughly understand the natural laws governing air movement, the benefit derived from control of the factors that affect circulation was a matter of chance; full advantage of any one factor was rarely obtained.

TIME IN THE KILN

The time required for drying green pine lumber varied with the grades of stock and the drying conditions used and to some extent depended upon the stock separation (p. 45). Sap stock required the longest time. No. 1 Common and Better lumber, which is largely sapwood, was being dried in a minimum period of 72 hours, which seemed to be the popular idea of the usual drying time of all 1-inch stock. Observation, however, brought out the fact that a large proportion of this grade was actually in the kiln from 84 to 96 hours. The lower grades contain more heartwood, which has less moisture than sapwood, and, having a higher final moisture content, were being dried in from 48 to 72 hours when separated from the upper grades.

MOISTURE CONTENT OF KILN-DRIED STOCK

Tests on the moisture content of kiln-dried stock at various plants, immediately after it had left the kiln, brought out the fact that overdrying was a common occurrence, although expediency often required that stock be removed from the kiln while still underdry. In several lots of B and Better stock tested the average values of moisture content were respectively 2.7, 5.4, 5.5, and 4.0 per cent, and in an underdry load 13.2 per cent. In the dry stock most of the pieces were below 5 per cent moisture content, some as low as 0.8 to 2.0, and an occasional piece was 9 to 10 per cent. In the underdry load mentioned the values ranged from 5 to 21 per cent.

No instance was found where it was a part of plant practice to make positive moisture determinations, the stock being drawn from the kiln simply when the operator was satisfied that it was dry. He determined moisture conditions merely by snapping splinters, cutting into boards, rapping the pile, or, most often, by the time the stock had been in the kiln, practices satisfactory only when the results are checked regularly, at frequent intervals, by an accurate moisture determination, and not satisfactory even then in particular work.

Common grades when dried with the upper grades had about the same moisture content as the upper-grade stock. When dried separately, common stock was pulled out after a shorter time in the kiln and consequently was not so dry.

Lack of uniformity in moisture content seemed to be characteristic of all plants; it was not uncommon to find in some parts of a pile stock that was "burnt up" while other parts were still underdry.

EXTENT OF DEGRADE CAUSED BY KILN DRYING

The chief object in making the kiln-drying survey was to determine as far as possible the extent of and the cause for degrade in southern yellow pine lumber. Consequently degrade tests were made at a number of plants in accordance with a method that will be described later. The method of determination was such that only degrade caused by drying defects appeared on the records. The stock tested was dried in the usual manner in the kiln, was allowed to stand for 24 hours before going to the planers, and was then graded immediately behind the planer by an association inspector. The cause of degrade, such as checks, warp, or damaged knots, was recorded. The results of these tests are given in Table 1. This table shows, for instance, that, at mill 1, 78.8 per cent of the B and Better stock remained on grade, 15.1 per cent fell to No. 1 Common, 4.2 per cent to No. 2 Common, and 1.2 per cent to No. 3 Common. The remaining 0.7 per cent, which was trimmed off, was considered as waste. Thus 20.5 per cent was reduced one or more grades on account of drying defects of one kind or another. The actual loss of lumber was small, being less than 1 per cent. The significant loss, that in the value of the stock, was far from small, however, the average being \$6.15 per thousand board feet. The greatest loss came in the wider stock but, since the test was on mill-run width, the total loss was representative of mill-run B and Better stock at that plant.

TABLE 1.—*The extent and the cost of degrade of southern yellow pine lumber, as determined by grading behind the planers, caused by improper methods in kiln-drying practice at representative mills during 1922 and 1923*

Grade as placed in kiln	Item	Mill No. 1	Mill No. 2		Mill No. 3	Mill No. 4	Demonstration run
B and Better	Species of pine	Longleaf.		Shortleaf.	Shortleaf.	Shortleaf.	Shortleaf.
	Board feet graded	2,405		1,501	4,536	5,053	4,790
	Mill-run stock, size in inches	1 by 4 to 1 by 12		1 by 8 to 1 by 12	1 by 4 to 1 by 12	1 by 4 to 1 by 12	1 by 4 to 1 by 12
	Drying time ... hours	66		72	72	72	84
	Final grades: [1]						
	On grade ... per cent	78.8		71.1	86.7	76.7	94.2
	Degraded to No. 1 Common ... do	15.1		13.6	4.7	17.9	3.6
	Degraded to No. 2 Common ... do	4.2		8.0	6.7	5.4	2.0
	Degraded to No. 3 Common ... do	1.2		2.4			
	Waste ... do	.7		4.9	1.9		.2
	Loss per 1,000 board feet [2] ... dollars	6.15		11.64	4.55	5.88	1.76
No. 1 Common	Board feet graded	3,134	2,407	[3] 627	4,349	5,212	4,652
	Mill-run stock, size in inches	1 by 4 to 1 by 12	1 by 8 to 1 by 12	1 by 10	1 by 4 to 1 by 12	1 by 4 to 1 by 12	1 by 4 to 1 by 12
	Drying time ... hours	66	72	72	72	72	56
	Final grades: [1]						
	On grade ... per cent	54.9	50.3	91.2	83.8	72.3	88.4
	Degraded to No. 2 Common ... do	43.9	22.7	8.6	13.8	24.3	10.5
	Degraded to No. 3 Common ... do	.4	21.1		1.2	3.4	.8
	Degraded to No. 4 Common ... do	.4	3.5				
	Waste ... do	.4	2.4	1.2	1.2		.3
	Loss per 1,000 board feet [2] ... dollars	7.30	9.51	1.74	3.14	4.64	2.01
No. 2 Common	Board feet graded	2,307			4,744	4,374	4,913
	Mill-run stock, size in inches	1 by 4 to 1 by 12			1 by 4 to 1 by 12	1 by 4 to 1 by 12	1 by 4 to 1 by 12
	Drying time ... hours	66			72	72	56
	Final grades: [1]						
	On grade ... per cent	73.4			64.7	72.9	87.9
	Degraded to No. 3 Common ... do	24.9			34.6	27.1	11.8
	Waste ... do	1.7			.7		.3
	Loss per 1,000 board feet [2] ... dollars	1.70			1.88	1.23	.62

[1] Defects caused by imperfect manufacture were not considered in determining the degrade caused by drying.
[2] The reductions in value are based on the Southern Pine Association's sales report of Mar. 10, 1923.
[3] This stock was bulk piled for 30 days. All other stock was manufactured 24 hours after leaving the dry kilns.

The degrade and waste for No. 1 Common stock, 45.1 per cent, was considerably greater than for B and Better; the loss averaged $7.30 per thousand board feet. The degrade in No. 2 Common, on the other hand, does not represent so great a monetary loss even when the percentage of degrade is as high as in the upper grades, because the difference in value between No. 2 Common and No. 3 Common is much less than that between No. 1 Common and No. 2 Common, or between B and Better and No. 1 Common.

The tests on the same grades at other mills varied somewhat, but in the main were consistent with the degrades at mill 1. The big difference between the B and Better stock at mill 1 and at mill 2 is one of width, the wide stock degrading more than the narrow.

BULK PILING

Some mills had rough storage sheds in which the kiln-dried stock, particularly the upper grades, was held in bulk for a period before manufacture. Where this practice is followed the degrade is not so great as where stock is run direct from the kiln to the planer. Since at that time bulk-piling stock after drying it was not common, the practice was omitted from the study included in the survey of 1922.

CONCLUSIONS DRAWN FROM SURVEY

To sum up the situation as it appeared after the 1922 survey, the degrade caused by the seasoning practice then current was altogether too high, drying conditions were too harsh, and very few of the millmen appreciated the fact that there was something more to drying than merely evaporating the moisture in the wood. No serious attempt was being made to control drying conditions, to learn what drying conditions existed in the kiln, or to ascertain what such conditions meant in terms of grade reduction and loss in value.

Since 1922 conditions have improved at many of the mills visited and, of course, at many of those not visited. New kilns have been built and old ones modified, temperature-control and humidity-control apparatus has been installed, and the personnel have a better idea of how to keep drying losses under some control. Unfortunately, there still are many mills where conditions have not been improved and others where some alterations in kilns and equipment have been made with little or no resultant improvement. The mills that have forged ahead have done so because their executives recognized that an understanding of the principles of drying was necessary for the best results and set about improving both personnel and kilns in order that such principles could be understood and followed.

EXPERIMENTS AT COMMERCIAL PLANTS

EXPERIMENTS ON SHORTLEAF PINE

The 1922 survey had shown that the severity of the current drying conditions was largely responsible for the degrade in kiln-dried lumber. The initial step in reducing such degrade was to determine (1) the temperature and the humidity that would give the best results, and (2) the practicability of obtaining such conditions in commercial kilns. Accordingly one of the progressive kilns at a plant in Texas was modified by installing steam sprays at the dry end for humidity control, and certain minor changes were made in the heating coils. Automatic temperature and humidity control was installed with the object of operating the kiln under a drying schedule that used humidities higher than those normally secured at that time in the average natural-circulation kiln. Subsequent experiments demonstrated that it was possible, by using higher final humidities, to dry B and Better stock with a degrade of about one-fourth the amount generally obtained but that the drying time exceeded the time required in the regular kiln. The influence of the higher final humidities on the circulation in the kiln and the effect of the circulation itself on the rate and the uniformity of drying will be described later. It will be sufficient here to say that, in natural-circulation kilns, circulation decreases as the humidity increases, and rapid and uniform drying requires a good circulation. In the modified natural-circulation progressive kiln used in the experiments it was impossible to get sufficient circulation when maintaining the higher humidities required for the common grades, and such stock, when dried so as to obtain a lower degrade, could not be dried in this kiln within a reasonable time.

The experiments demonstrated the need for further tests in a kiln equipped to provide a greater circulation than that obtainable by natural means in the ordinary type of progressive kiln. It was decided that best results could be obtained when the kiln circulation was independent of humidity.

Consequently another lumber company, also in Texas, turned over one of their kilns for the purpose and it was remodeled into a forced-circulation compartment kiln and was equipped with temperature-control and humidity-control devices. A series of tests on shortleaf pine was made in this kiln; the results, when compared with the previous experiments, indicated a marked improvement in the quality of the stock both in B and Better and in the common grades. The time of drying, despite the higher relative humidities used, was perhaps a trifle less than that required in the natural-circulation kilns.

EXPERIMENTS ON LONGLEAF PINE

Since both the kiln-drying experiments just described had been made on shortleaf pine, it was deemed advisable, because of characteristic differences in the species, to make a distinct set of experiments on longleaf. This work was undertaken at a plant in Alabama in the spring of 1926. Some drying and degrade experiments made at the same plant two years earlier (1924) had brought out the fact that no real improvement in the operation of the existing kilns could be secured without more or less modification of the kilns themselves. The kilns, 82 feet long, were too short to work properly as natural-circulation progressive kilns under the existing distribution of heating surface and system of ventilation. Accordingly, after consideration of several possible methods of modifying them, including both natural and forced circulation, one kiln had been remodeled into an internal-fan compartment kiln and equipped with automatic-temperature and humidity-control devices, and its successful operation had led to the later remodeling of seven others in the same way.

The 1926 experiments were of somewhat broader scope than the 1924 tests, in that stacking and stickering methods, storage subsequent to kiln drying, and machining problems were also included. In addition to the general experiments conducted in cooperation with the Southern Pine Association, a considerable number of independent tests have also been made as opportunity offered.

CAUSES OF DEGRADE

The grading rules define the defects that establish the grade into which a board will fall. Some of these defects, such as knots and pitch pockets, are natural, existing in the living tree; others, such as wane, occur in manufacturing; while still others, such as end and surface checks, are caused essentially by the drying process. Certain other defects, such as planer splits, are due partly to drying and partly to other causes.

The criterion of good drying is small seasoning degrade and stock having a moisture content suitable for the purpose for which it will be used. Further, the stock should be free from injurious internal stresses and its strength properties should be substantially unimpaired. Any workable means of improving drying practice, thus reducing degrade, returns an immediate profit to the manufacturer. In the practical side of experimental work in the drying of southern yellow pine the object has been principally to learn the nature, cause, and extent of drying defects as they appear in the degrade and the amount of degrade and also to determine to what degree such defects may be reduced. The means used for reducing degrade, fortunately, are the same as those required to obtain greater uniformity in moisture content.

DEFECTS THAT APPEAR IN KILN DRYING

The defects chargeable to the drying process may be grouped under the five heads that follow:

CHECKS AND SPLITS

Checking and splitting are the principal causes of degrade in all grades, but are of particular importance in B and Better stock. These defects may appear either in the kiln, during drying, or at the planer. Checks and splits that develop during seasoning occur when the surface of the board dries faster than the interior and attempts to shrink before the interior is ready to shrink; as a result the surface fibers tear apart. Splits that develop at the planer come from cupping, twisting, casehardening, or brittleness caused by overdrying. They occur when the piece is flattened on the bed of the planer.

IMPERFECT KNOTS

Loose, checked, and broken knots are an important source of degrade in the common grades. As explained on page 13, the knot in shrinking tends to become smaller than the knot hole. Live knots, if firmly grown into the surrounding wood structure, may only check, but encased knots will become loose if sufficient shrinkage occurs.

WARPING

Such defects as cup, crook, and twist are caused by variations in shrinkage within the board affected. Cupping is particularly serious, since cupped stock is likely to split when going through the planer. Crook is usually caused by unequal longitudinal shrinkage between the two edges of the board; it occurs principally in stock that has been cut from trees having compression wood. Page 10 presents more information on compression wood and its effects.

UNDERDRYING AND OVERDRYING

Stock that is underdry is very likely to shrink further, and consequently such a condition is objectionable, especially in upper-grade stock. Improper kiln operation and poor stacking on kiln cars are the most common factors responsible for this defective condition. Overdry stock is brittle, and brittleness contributes to checking and splitting. Such stock also may swell after planing, an undesirable condition in high-grade flooring and finish.

Operators ordinarily intend to dry upper-grade 4/4-inch lumber to a moisture content of from 7 to 10 per cent, and lower grade to a moisture content of from 12 to 18 per cent. When so dried the stock is commonly considered suitable for the use requirements of the respective grades. Underdry stock naturally has a moisture content above the high limit for its grade.

CASEHARDENING

Casehardening contributes materially to drying degrade, but it is usually associated with one of the other causes in such a manner as to make recognition of the real offender difficult for the uninitiated.

Casehardened lumber cups when resawn or when more is dressed off one side than off the other. (Pl. 2, A.) In southern yellow pine the condition becomes apparent when resawing any thick stock and when resawing stock for bevel siding. The pinching in of the grooves in flooring and other matched items is also evidence of casehardening. The most serious result of the internal stresses, particularly in cupped stock, is the weakening of the wood, which causes a larger percentage of boards to split in the planer than is the case in boards that are not casehardened.

METHOD OF GRADING

The grading in the drying and degrade experiments at commercial plants was done by an official inspector of the Southern Pine Association and the tallies were so kept that the recognized defects causing degrade could be segregated.

In some of the earlier experiments the stock was graded both green and dry. In the 1926 studies the stock was not graded at the green chains, but, after drying and machining, was graded and tallied at the dry chains on the basis of the grade that it had had when green, and was then charged with any change in grade that had developed during drying and manufacture. Only those defects that had been caused by drying or were related to drying were considered in this test; the grader was instructed to use his best judgment in establishing both green and final grades so that they would register the defects with which the study was concerned. Wane, imperfect manufacture, and pitch pockets, for instance, are not seasoning defects and therefore pieces containing such defects were tallied as of their original green grade unless the grade had been lowered by seasoning defects. Stock undergoing these tests was not ripped after kiln drying to raise grade but was run in the same widths in which it was dried. Where a trim would have raised the grade above the green grade, the piece was tallied as of its green grade and if trimmed because of a drying defect the trim was also charged against the piece. For a combination of drying defects resulting in degrade the cause of the degrade was charged to the most consistent defect or to the defect occurring most frequently.

Occasional pieces, for which the cause of degrade was questionable or could not be determined at a glance, were pulled from the chains and graded later.

Except for matched flooring, ceiling, and siding it is more or less immaterial, for a degrade investigation, whether the stock is run into a pattern or only surfaced four sides. For simplification and accuracy the stock examined was grouped under the grades B and Better, No. 1 Common, and No. 2 Common, thus avoiding the complication of intermediate grades.

It was intended that each size and grade should include enough material to be representative of that particular stock; a minimum of 2,000 board feet was desired and 4,000 to 5,000 feet was usually obtained. In a few instances, however, there was not enough material available at the time the kiln trucks were being loaded to make up the minimum desired.

LOSS CAUSED BY INFERIOR KILN DRYING

Table 2 on page 40 shows briefly the cost of inferior kiln drying of southern yellow pine as determined by means of the experiments at commercial plants here reported. The lumber prices from which the losses were calculated are practically identical with the corresponding January, 1929, lumber prices; this statement applies also to the other prices used for this bulletin.

CONTROLLING KILN DEGRADE

In devising methods of control over the factors that cause kiln degrade it is necessary to divide the preparation of stock for the planer into three principal steps, so that the influence of each one on the ultimate degrade can be studied independently of the others. The lowest possible degrades are obtained only when each step follows the best known practice. The logical divisions follow:

Piling, including stickering, in loading the kiln trucks.
Drying conditions in the kiln: Temperature, humidity, and circulation.
Storage after kiln drying and before planing.

Numerous experiments have demonstrated that improvement in the practice of any one of these factors, independent of the others, will definitely reduce drying degrade. If the stock can be properly conditioned by steaming before it leaves the kiln, however, storage after kiln drying is not necessary or even advantageous in preventing degrade; the stock may then be run direct from the kiln to the planer.

PILING

Certain kinds of defects, such as cup and twist, are a result of poor stacking, quite independent of whether the kiln-drying methods proper are good or poor. These defects increase the amount of checking, splitting, and torn grain, and the number of broken knots. Good stacking with plenty of stickers reduces crook, holds the stock flat, and is an important factor in the prevention of degrade regardless of other conditions in the kiln.

KILN OPERATION

Careful seasoning in kilns where drying conditions can be accurately controlled is probably the most important factor in holding kiln degrade to a minimum. Checks and splits during drying may thus be avoided and overdrying prevented, thereby reducing planer splitting and damage to knots. Relief of casehardening, uniformity of moisture content, and less pitch on the surface of the boards also play their part in producing stock in the best condition for manufacture and use.

CONDITIONING BEFORE MACHINING

Storage of rough stock after kiln drying and before planing has an effect similar to that obtained by conditioning in the dry kiln. Where kilns are not provided with means for steaming the stock before it is removed from the kiln, or are not of a design that permits such treatment, storage is beneficial, especially if the stock remains in the shed for periods upward of three weeks.

ECONOMIC LIMITATIONS

The limitations surrounding the kiln-drying practice at many southern pine mills are such that it may not be economically advisable to make all of the changes required for holding degrade to the absolute minimum. It is rare, however, that improvement in the practice of at least one of the three main factors is impossible. The advantages and the limitations of control over these independent factors will be considered separately, beginning with the design of the kiln and its effect on drying conditions.

TYPES OF KILNS FOR SEASONING SOUTHERN YELLOW PINE

SMOKE AND FURNACE-HEATED KILNS

In the southern pine region approximately half of the cutting is done by small portable or semiportable mills for which it seems impracticable or unprofitable to install a steam kiln for the usual period of operation on any one site. A large part of the cut of these small mills is sold green or air seasoned, while some is collected in concentration yards or is sold to large mills where kilns are available.

In the shortleaf pine areas, particularly in Arkansas, many of the small mills use smoke kilns. Such a kiln consists of a loosely built platform set on posts and about 8 feet or more off the ground, with boarding on three sides above and on three or four sides below it. Lumber is piled on stickers on the platform, sometimes flat and sometimes on edge, and a fire is built on the ground beneath it, the smoke passing upward through the lumber pile. The lumber, of course, is darkened by the smoke, but the discoloration is dressed off when the stock is planed.

This type of kiln permits the small operator to dry his stock more rapidly than he could by air seasoning. Rapid drying, among other desirable results, reduces the probability of blue-stain attack. Sometimes the material accumulates slowly and several days will elapse while the kiln is being loaded and before the fire is started. Blue stain is very likely to develop during this period and also during rainy weather, when it seems impractical to keep the fire burning.

The drying time for 1-inch southern yellow pine stock in a smoke kiln is variable, although it usually is three to four days. The degree of drying, as might be expected, is also variable; the drying is irregular, not only in different parts of the pile but sometimes even within the same board. At one time smoke-dried lumber was in popular demand, but within recent years, because of the higher standard of seasoning required by the buyers and the general improvement in the standard of seasoning in steam-heated kilns, smoke-dried stock has often been sold at a price considerably below that of stock from steam-heated kilns. The usual type of smoke kiln offers such slight opportunity for control of drying conditions that there is little hope for improvement in the seasoning process proper. Some improvement in the product, however, may be obtained by improving the stacking. Storage after drying will also help to equalize the moisture content, particularly in stock that has been dried to a relatively low moisture content.

The furnace kiln differs from the smoke kiln in that the fire is built in a fireplace or fire pot of metal or brick and is fed from the outside of the kiln. The fire pot and the smoke flues, which are looped around within the kiln below the lumber pile, act as radiators to heat the air. The smoke is exhausted through chimneys instead of passing through the lumber. The kiln building is a tight inclosure and when the fire is carefully tended a fair degree of temperature control is possible. Humidity control, however, is more difficult to obtain. Tight construction and dampered intake and exhaust flues offer an opportunity to retain some of the moisture evaporated from the lumber, but this method is usually inadequate. If steam is available it should be used in the same manner as when humidifying steam-heated kilns.

STEAM-HEATED KILNS

Steam is the medium most commonly used for heating dry kilns, because of the very numerous advantages it offers in comparison with other means. It is employed in all the types of kilns included in the following discussion.

Steam-heated dry kilns in the southern pine region may be separated into two groups, progressive and compartment. While it appears at first that the difference between progressive and compartment kilns is essentially that of the method of loading, actually there are also very important differences in design which, in turn, have quite an important bearing on the method of operation best suited to the stock being dried. These differences will be taken up in detail later.

Both progressive and compartment kilns may also be classified, in accordance with the principle of circulation employed, as (1) natural circulation, (2) forced circulation, which is sometimes called "mechanical circulation," and (3) combined natural circulation and forced circulation.

PROGRESSIVE KILNS

The progressive kiln holds a number of unit charges of lumber, which are in different stages of drying; each unit charge consists of about one-third or one-fourth the total capacity of the kiln. When a unit charge has dried and has been removed, a fresh one of green lumber is introduced into the opposite end of the kiln; this unit then passes by stages from the charge or green end to the discharge or dry end, eventually emerging as "dry" lumber. The design of this kiln intends that the drying conditions, as well as the movement of the unit charges, shall be progressive, the mild conditions obtaining at the green end and the most severe at the dry end.

COMPARTMENT KILNS

In compartment kilns a single charge occupies all of the loading space and drying conditions are intended to be uniform throughout the kiln at any given moment. The drying conditions are changed from time to time in conformity with the moisture condition of the stock or in accordance with a time schedule.

NATURAL CIRCULATION IN STEAM-HEATED KILNS

Natural circulation in steam-heated kilns is brought about by differences in temperature; the steam in the coils supplies heat and evaporation from the lumber consumes it. The heated air tends to rise from the coils and the air cooled by evaporation tends to sink. If the arrangement of the lumber and the heating coils is such as to facilitate this movement, a very definite circulation will exist as long as drying takes place.

Heat losses through doors, roofs, and outside walls produce local cooling effects, which add to the general air movement, but these effects vary more or less in accordance with the outside atmospheric conditions and in consequence are unreliable and are therefore more of a hazard than a benefit. Because the kiln is much hotter than the temperature of the air outside, there is a constant leakage of heated air from the upper part of the kiln and of cold air from the outside into its lower part. Vents, flues, or chimneys are provided to facilitate the escape of some of the air from the kiln because it carries with it the moisture evaporated from the wood. Fresh-air inlets may also be provided in the bottom of the kiln to admit air to replace that escaping through the chimneys. If no fresh-air inlet is provided, replacement is dependent upon inleakage through cracks and crevices in the walls and around the doors.

The amount of air passing through the average natural-circulation kiln, entering the intake ducts and going out through the chimneys, has been calculated as less than 5 per cent of the air that is in motion in the kiln. Increasing the number and the size of the inlets and the exhaust flues for the purpose of increasing the air flow would have very little effect on circulation but would increase steam consumption. In natural-circulation kilns, therefore, the amount of air movement produced by passage of air through the kiln and out of the chimneys may be considered an unimportant part of the total. The whole purpose of exhausting air from the kiln is to carry away the evaporated moisture; the ideal condition would be reached if it were possible to control the chimneys and flues with dampers so regulating the flow that the moisture would be carried away only as fast as it evaporates, thus holding the humidity at the value required by the schedule.

The circulation through the piles of lumber represents the bulk of the moving air. Its natural direction is vertical, either upward or downward; it will move horizontally only to the extent that its natural direction is opposed. Such opposition may result from the manner of piling or from counter air currents.

NATURAL-CIRCULATION PROGRESSIVE KILNS

The characteristics of natural circulation in a southern pine progressive kiln are illustrated in Figure 6. Hot-air exhaust flues and cold-air intakes differ more or less in location according to the make of the kiln and, since their position has no important effect on the principal air movement, they are left out of this illustration. Because some means must be provided for the removal of evaporated moisture, however, both intake and exhaust flues are assumed to exist. The total kiln charge of 15 trucks comprises 3 unit charges of 5 trucks each, the charge at the green end representing stock loaded less than 1 day, the middle charge less than 2 days, and the dry-end charge less than 3 days; each charge is to be removed after 3 full days in the kiln. As the heat required for evaporation is extracted from the air surrounding the individual pieces of lumber, the air becomes cooler in proportion to the amount of moisture evaporated. Where evaporation is rapid and considerable cooling takes place, the air movement is downward through the lumber pile even when the heating coils are in the path of this movement. Even if the coils are in the path, the weight of the column of air above is great enough to counterbalance the influence of the heat added by them, and the air continues to pass downward through the coils in order to rise where it meets less resistance to an upward movement, as, for example, between the pile and the wall, or at the dry end of the kiln, where evaporation is less rapid.

Evaporation from the relatively wet lumber at the green end of a progressive kiln is very rapid, and consequently the air movement is downward. (Fig. 6.) The same direction of movement also exists in the middle charge but, since this stock has lost much of its moisture, evaporation is somewhat less rapid and the rate of movement is

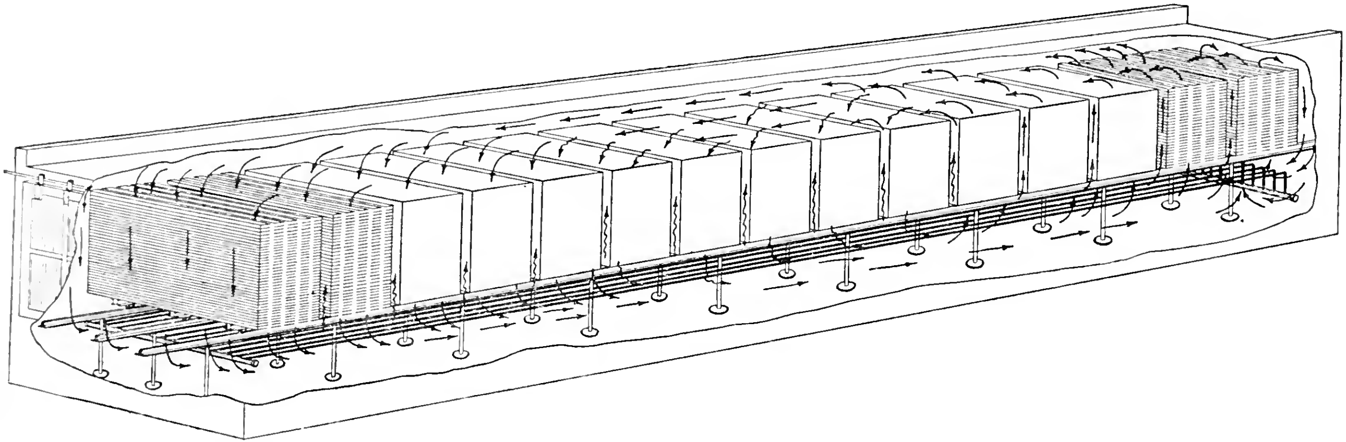


FIGURE 6.—A cross-piled natural-circulation progressive kiln in perspective. The lumber moves from left to right, whereas the main longitudinal air circulation above the rail level is in the reverse direction. In addition there are minor local currents of air up and down through the lumber, as indicated by the arrows; the wavy arrows indicate sluggish air movement. The cooling effect of each door produces local downward circulation at the extreme ends of the kiln. Since the principal movement of air in natural-circulation kilns is vertical, for both the progressive and the compartment types, the stickers do not oppose the main circulation with either end piling or cross piling

reduced proportionately. The charge in the dry end is nearly dry, little evaporation is taking place, and here circulation will be upward. It sometimes happens that stock passes through the first and the second day's positions and reaches the final position while still containing considerable moisture. In such cases the circulation has been found to be downward even at the dry end, until the stock became relatively dry. When this stock has dried sufficiently the air movement reverses, the air then flowing upward.

Ordinarily most of the air that descends in the first and the second position of the daily charge finds its way upward through the load in the third position, but some works up along the side walls or in any open spaces resulting from short lumber in the loads. The general movement is a cycle, downward at the green end to some point below the steam coils, along the kiln to the dry end, and then upward, returning along the ceiling to the green end.

Heat losses through the roof and the doors of a progressive kiln have some effect in modifying conditions locally. The principal effect of the roof loss is that it lowers the temperature of the air moving from the dry to the green end, a condition that is more or less beneficial. Cold drafts from the doors are rather objectionable, particularly at the dry end where such cold air, mixing with the hotter air returning from the green end, cools the portion it joins and consequently produces a lower temperature in any load it may pass through, thus interfering somewhat with drying conditions; these drafts usually affect the load nearest the door.

NATURAL-CIRCULATION COMPARTMENT KILNS

The characteristics of natural circulation in a southern pine compartment kiln are illustrated in Figures 7 and 8. Here again, as with progressive kilns, hot-air exhaust flues and cold-air intakes are left out of the drawing, but are assumed to exist. Figure 7 illustrates a kiln with cross piling and Figure 8 shows one with lengthwise piling.

The factors that create natural circulation, which are the heat supplied from the steam coils, the consumption of heat in evaporation, and heat losses through roof, walls, and doors, are the same in compartment as in progressive kilns. However, there is one important difference between the two types that affects the volume of air moved as a result of the cooling effect resulting from evaporation. Since this volume includes most of the air in motion it has an important effect on the rate of drying, an effect that is in favor of the progressive kiln. The greater the difference between the temperature of the ascending air and that of the descending air, the greater will be the velocity of movement. The difference in temperature is definitely limited by the drying schedule used, in that after the lumber is once warmed up to kiln temperatures the lowest possible temperature, as a result of evaporation, is the wet-bulb temperature. For example, following the initial conditions for warming the stock, a certain schedule (No. 107, p. 43) calls for a temperature of 190° F. and a relative humidity of 63 per cent, for which the wet-bulb temperature is 170°. (Fig. 9.[11]) In this temporary condition the lowest possible

[11] See footnote 4 on p. 2; refer to Table 1 in Bulletin 1136 (5).

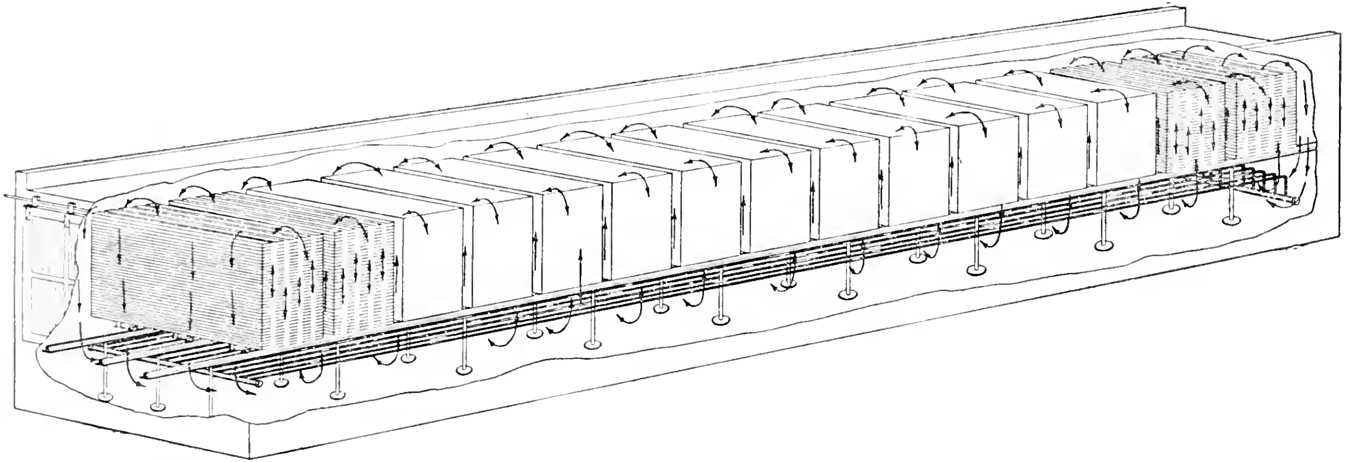


FIGURE 7.—A cross-piled natural-circulation compartment kiln in perspective. The arrows indicate the direction of the main circulation, which is vertical-lateral. During the early part of the run, when evaporation is rapid, the air movement is downward in the pile, through the heating coils, to the space at the side walls or to other unobstructed vertical channels, upward, and into the pile to repeat the cycle. During the final stage of drying, the heating coils, which are immediately below the lumber, overcome the circulatory effect of the evaporation, which has now become slow, and the main circulation then reverses, as shown by the double-headed arrows. Heat losses through the doors produce local downward circulation at the extreme ends of the kiln. Since the principal movement of air in natural-circulation kilns is vertical for both the progressive and the compartment types, the stickers do not oppose the main circulation with either end piling or cross piling

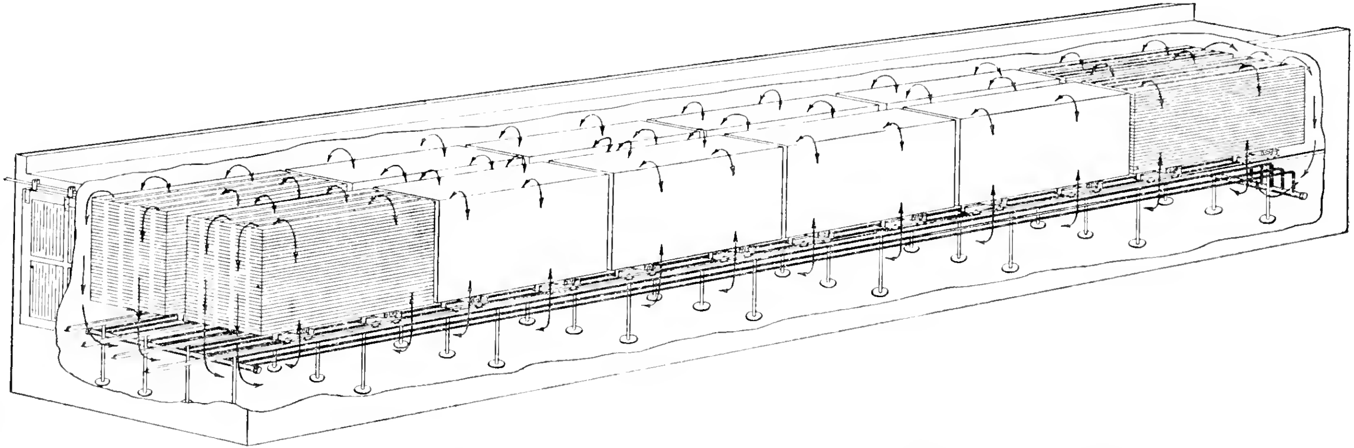


FIGURE 8.—An end-piled natural-circulation compartment kiln in perspective. The arrows indicate the direction of the main circulation, which is vertical-lateral. During the early part of the run, when evaporation is rapid, the air movement is downward in the pile, through the heating coils, to the space between piles and to that at the side walls or to other unobstructed vertical channels, upward, and into the pile to repeat the cycle. During the final stage of drying, the heating coils, which are immediately below the lumber, overcome the circulatory effect of the evaporation, which has now become slow, and the main circulation then reverses, as shown by the double-headed arrows. Heat losses through the doors produce local downward circulation at the extreme ends of the kiln. Since the principal movement of air in natural-circulation kilns is vertical, for both the progressive and the compartment types, the stickers do not oppose the main circulation with either end piling or cross piling

temperature as a result of evaporation would be about 170°. Under the established drying conditions that follow it would be nearer 175°, a matter of 15° difference between the highest and the lowest temperature in the pile. In a progressive kiln operating on the same schedule the temperatures would be about a maximum of 210° where the air enters the pile at the dry end and a minimum of 175° where it leaves the pile at the green end, a difference of 35° between the highest and the lowest. Obviously the air movement possible in the progressive kiln is far greater than that in the compartment: such an air move-

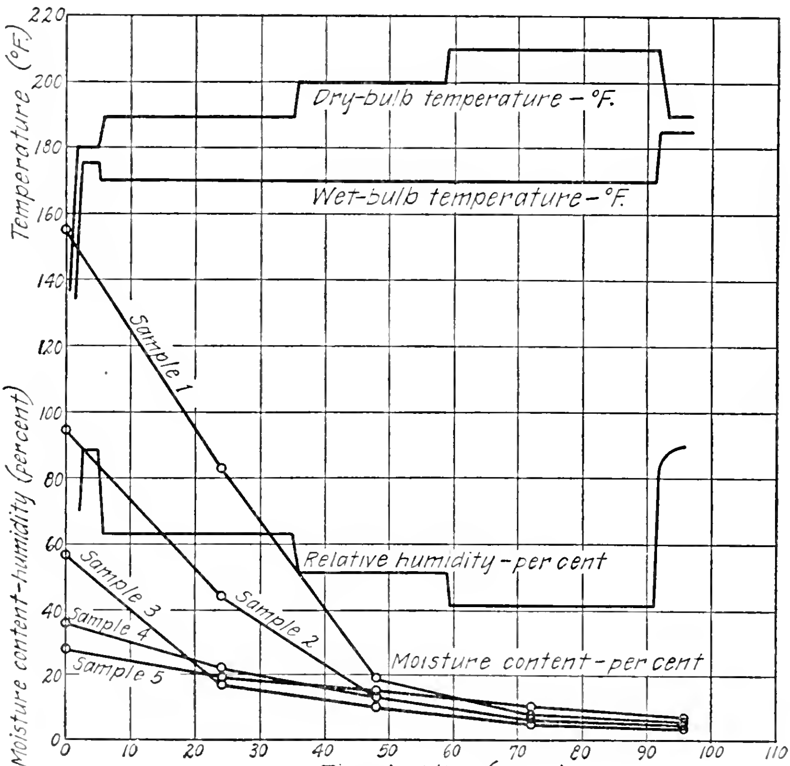


FIGURE 9.—The plotted record of a kiln run that followed Schedule 107 (p. 43) accurately. The lower graphs show the changes in the moisture-content values of representative kiln samples. They show also that the humidity specified in the schedule was high enough to reduce the drying rates of the rapidly drying pieces to values that agreed reasonably with the rates of the slow drying pieces, thus avoiding overdrying, in accordance with the purpose of the schedule

ment is invariably found in the progressive kiln in spite of the longer travel necessary for the air to complete its cycle of movement. Hence at relatively high humidities, such as those during the early part of a run, the compartment kiln does not obtain the air velocity possible in a progressive kiln.

During the final stages of drying, when the schedule selected for illustration permits a temperature of 210° F. and a relative humidity of 44 per cent, which comes to a wet-bulb temperature of 170°, the compartment kiln is still at a disadvantage. By this time the stock is comparatively dry and the evaporation is slower, so instead of cooling to 175° the air will seldom cool below 195°.

In an attempt to obtain an equal rate of drying, most southern pine natural-circulation compartment kilns are actually operated under schedules much more severe than those for progressive kilns. This practice is unwise, since the resulting conditions are likely to cause heavy degrade.

The direction of air movement in the cycle characteristic of compartment kilns is vertical-lateral. During the time when evaporation is rapid the movement is downward in the pile, through the heating coils, to the space at the side walls or to other unobstructed vertical channels, upward, and into the pile to repeat the cycle. During the final stage of drying the heating coils, which are immediately below the lumber, overcome the circulatory effect of the evaporation, which has now become slow. The circulation then reverses, the air moving upward from the coils into the pile, across to the space at the side walls or to similar openings, downward, and back to the coils.

Heat losses through the doors of a compartment kiln cause a downward movement of air at the ends of the kiln to the space below the rails, where the cold stream joins the regular lateral circulation below the end trucks. The effect is to lower the temperature materially, and consequently it is quite common to find the lumber in this space underdried when the rest of the charge is thoroughly dry. Heat losses through the side walls and the roof are relatively uniform along the kiln and do not necessarily interfere with the drying conditions if the heating surface provided is sufficient to offset the loss.

EFFECT OF HUMIDITY ON NATURAL CIRCULATION

It has been explained that the movement of air increases as the difference between the wet-bulb and the dry-bulb temperatures increases; that is, the lower the humidity, the better the circulation. Good drying practice requires that suitably high humidities be maintained throughout the drying period, particularly during the early stages of drying. If the proper humidity is maintained, it evidently will be at the expense of natural circulation. This fact, in turn, will result not only in slower drying but also in irregular drying unless the drying time is extended. In an experiment in a natural-circulation progressive kiln it was found that the drying period for No. 1 Common and Better stock was increased from 72 to 84 hours by changing from the low humidities previously employed by the operators to high ones. The degrade for the high-humidity drying, however, was only about one-fourth that for the low-humidity schedule.

In the common grades of knotty stock relatively high final humidities are required to keep degrade at a minimum, and natural circution consequently is inadequate.

FORCED CIRCULATION IN STEAM-HEATED KILNS

Forced circulation in steam-heated kilns is commonly obtained by means of fans or steam jets, or both. When fans are used they may be either outside of the kiln in a special housing, connected to the kiln by supply and return ducts, or may be inside of it, usually in ducts or in housings intended to distribute the air according to the design of the kiln. When steam jets are used, high-pressure steam is allowed to escape through small orifices in steam spray pipes, or through special nozzles. Here again the design of the kiln presumes that the circulation is to follow a certain path, either steadily or in cycles, and the spray pipes or nozzles are so located as to accomplish this purpose. Although steam-spray pipes offer one of the most simple expedients to augment natural circulation, the results are not always fully satisfactory.

Guidance of the moving air is required in kilns having circulation created entirely by mechanical means. Such guidance may involve baffles along the uninclosed air passages that always are necessary in every kiln. When baffles are used they must be located with considerable care in order that the flow of air may be uniform throughout each lumber pile. In both progressive and compartment kilns the air velocity must be restricted to a value that can be controlled as desired.

COMPARISON OF NATURAL AND OF FORCED CIRCULATION

From the foregoing discussion of circulation the matter of adequacy of air movement in a steam-heated kiln drying southern yellow pine lumber may be summarized as follows: Natural circulation is adequate in progressive kilns for the drying of upper-grade stock. It does not provide enough circulation in compartment kilns for any grade nor in progressive kilns for the lower grades. "Adequate circulation" in such a dry kiln may be defined as an air movement sufficient to permit the maintaining, throughout the drying period, of drying schedules closely approximating those given in this bulletin. Hence adequate circulation means reasonably uniform drying and the minimum period in the kiln that is consistent with minimum degrade. It follows, therefore, that inadequate circulation means a lack of uniformity of drying, a longer drying period, greater degrade, or a combination of the three. Common practice in such kilns is to use humidities lower than those recommended, in order that drying may be hastened and inequality in drying minimized; such practice largely disregards the degrade that results from the more severe drying conditions.

Natural-circulation kilns, both progressive and compartment, are still the type most common in the South. On the other hand, the modern trend of design of commercial kilns for southern yellow pine is to embody some more or less positive form of circulation created mechanically and intended to operate in conjunction with the natural circulation. Such design is planned to provide a sufficient amount of air movement during all stages of drying, quite independent of humidity. When steam is used to stimulate the circulation, however, it of course increases the humidity and, conversely, when it is used to control the humidity it should be released in such a manner that it will also stimulate the circulation.

KILN OPERATION

FAULTS COMMON IN KILN OPERATION

LACK OF CONTROL OF DRYING CONDITIONS

Most of the older dry kilns used by southern pine manufacturers are of the natural-circulation progressive type, though there are a few scattered instances of compartment kilns. In most of the older kilns the operation consists of loading, and then leaving the kiln to itself until the stock is dry and ready to unload. No particular attempt is made to control temperatures and humidities. In such cases the temperatures in progressive kilns are lowest at the charge end because of the rapid evaporation from the green lumber. As the lumber becomes drier and progresses toward the discharge end less evaporation takes place and the temperatures are higher. After loading, the temperature at the green end rises rapidly to about 150° F., but during the first 24 hours it seldom goes above 170° to 175°. There is usually from 20° to 40° difference between the temperatures at the two ends. Immediately after loading, the relative humidity is comparatively high at the green end, sometimes near 100 per cent, but a few hours after loading it is usually below 50 per cent at the green end and below 20 per cent at the dry end. If the relative humidity in the kiln were 100 per cent, no evaporation would take place, no change in temperature would come from that source, and consequently no circulation would follow. Conversely, the lower the humidity the greater the possible differences in temperatures and therefore the greater the air movement.

EXCESSIVELY LOW HUMIDITY

The humidity in pine kilns not provided with steam sprays or some other means of humidifying is ordinarily very low. The only moisture available to raise the humidity is that evaporated from the lumber, and it can escape from the kiln in the form of vapor through ventilators, chimneys, and crevices, leaving the humidity in the kiln a natural balance between the rate of evaporation and the rate of escape.

While a low humidity is useful in producing natural circulation, it is the condition that causes checking, overdrying, casehardening, and damage to knots. On the other hand, if the humidity is raised either by closing dampers or by use of steam sprays that do not create circulation, the drying time in the kiln lengthens and underdry stock is often found. Less degrade, however, is likely to occur with high humidity than with low, although kiln operators usually follow the low-humidity method of operation.

The following example is an instance observed in a low-humidity progressive kiln in which a charge of 4/4-inch No. 1 Common and Better longleaf pine was dried in four days. Immediately before the placing of fresh charges the temperatures at the green end were nearly 200° F. and the relative humidities sometimes were as low as 20 per cent, while the temperatures and relative humidities at the dry end were about 220° and 15 per cent, respectively. After charging, and following the initial drop, the green-end temperature would rise in a few hours to 170° and the relative humidity would be about 35 per cent, and at the dry end these conditions would be 185° and 25 per cent, respectively. The following figures represent the rate of drying as indicated by six samples located in the outside tiers of the trucks: Moisture content, when loaded into the kiln, 74.6 per cent; after the first day, 34.8 per cent; after the second day, 7.8 per cent; after the third day, 5.0 per cent; after the fourth day, at the time of unloading, 2.7 per cent. The samples naturally represent the drying rate of the outer portion of the truck loads, some of the stock in the center of the piles drying somewhat more slowly. The figures show that for the stock represented 55 per cent of the total moisture lost was evaporated the first day and 93 per cent was evaporated by the end of the second day. These conditions are not at all exceptional but are actually typical at the majority of southern-pine plants where such kiln equipment is in use. The degrade observed in stock dried in this kiln may therefore be considered an example of the degrade occurring in plants having similar equipment.

REPRESENTATIVE DEGRADE LOSSES

Table 2 presents data covering representative degrade in stock dried in the kilns just described and run direct from the kilns to the planers. The stock had been flat piled in standard 16-foot trucks with six stickers to the course. If more stickers had been used the degrade would have been lower for reasons that will be given later. Even with better stickering, however, the harsh, severe conditions early in the drying process and overdrying in the final period would still have produced casehardening and brittleness. These in turn would have caused planer splitting and broken and loose knots comparable with the degrade losses referred to later in Table 9 (p. 56).

TABLE 2.—*Depreciation in value per thousand board feet of longleaf pine dried during 1924 in a natural-circulation progressive kiln with six stickers per course and run direct from the kiln to the planer*

Size of stock	Grade	Stock on grade	Stock degraded for—				Loss per 1,000 board feet [1]
			Splits	Trim	Knots	Miscellaneous	
Inches		*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	
1 by 6, 1 by 8, 2 by 10, 1 by 12	B and Better	85.20	10.92	3.45		0.43	$5.61
1 by 6, 1 by 8, 2 by 10, 1 by 12	No. 1 Common	66.40	20.40	3.15	10.05		8.74
1 by 6, 1 by 8, 1 by 10	No. 2 Common	54.60	24.10	.60	20.70		1.47

[1] Based on lumber prices substantially the same as those for January, 1929.

RESULT OF IMPROVING DRYING CONDITIONS

After the degrade tests just described, these progressive kilns were remodeled into compartment kilns equipped with automatic temperature and humidity control devices and a forced-circulation system was installed. The results of degrade tests on stock dried in accordance with Schedules 107 and 108 (pp. 43 and 44) and run direct from the kiln to the planer are shown in Table 3. The improvement over the results obtained before the kilns were remodeled (Table 2) is marked. This improvement may be attributed to the milder conditions during the early period of drying and the prevention of overdry stock by the use of more suitable final humidities. The B and Better and the No. 1 Common stock were in the same kiln charge. Their values of moisture content, averaged from eight samples, were as follows: When loaded into the kiln, 81.2 per cent; after the first day, 58.8 per cent; after the second day, 28.6 per cent; after the third day, 11.8 per cent; and after the fourth day, 6.8 per cent. The No. 2 Common stock was dried separately.

TABLE 3.—*Depreciation in value per thousand board feet of longleaf pine dried in a forced-circulation compartment kiln in accordance with Schedules 107 and 108, after piling with stickers 2 feet apart, and run direct from the kiln to the planer*

Size of stock	Grade	Stock on grade	Stock degraded for—			Loss per 1,000 board feet[1]
			Splits	Trims	Knots	
Inches		*Per cent*	*Per cent*	*Per cent*	*Per cent*	
1 by 6, 1 by 8, 1 by 10	B and Better	99.43		0.57		$0.36
1 by 6, 1 by 8, 1 by 10	No. 1 Common	97.65	1.62	.73		.72
1 by 6, 1 by 8, 1 by 10	No. 2 Common	94.79	1.86	.25	3.10	.58

[1] Based on lumber prices substantially the same as those for January, 1929.

A comparison of Tables 2 and 3 brings out the advantage resulting from accurate control of temperature and humidity, and positive and ample circulation. In many instances under observation steam sprays have been used to increase the circulation and at the same time to control the humidity in progressive kilns. In one such instance, after a careful study of the circulation distribution and of temperature and humidity throughout the kiln, a steam spray pipe was installed below the flat heating coils, about 35 feet from the dry end, with the sprays pointing toward the dry end. The steam supply to the spray was operated by the thermostat that controlled the humidity. Another thermostat controlled the temperature. A charge of 1 by 10 inch B and Better shortleaf pine in this kiln was degraded $2.09 a thousand board feet because of seasoning defects, while the same size and grade in an adjacent kiln, one without steam sprays but under temperature control, was degraded $3.66, which is about 75 per cent more. The stock in both cases was run through the planer 24 hours after leaving the kiln.

Of the two examples just given, one shows the increase in value of product that can be obtained through very accurate control of temperature and humidity and with ample circulation, and the other shows the corresponding increase secured through a much less positive form of temperature and humidity control and augmented natural circulation. Considering only economic matters, it would be futile to attempt to define the optimum degree of control of kiln conditions. It is clear, however, that any appreciable improvement in the control of these important seasoning factors will reduce seasoning degrade.

DRYING SCHEDULES

SELECTING DRYING CONDITIONS TO MINIMIZE SHRINKAGE

Substantially all the seasoning defects that affect southern yellow pine are caused directly by or result from unequal shrinkage within the piece affected; blue stain and pitch are the important exceptions. Hence the drying schedule should be arranged so that unequal shrinkage will be minimized as far as possible. It has already been pointed out that shrinkage begins at the fiber-saturation point, which for southern yellow pine is estimated at about 25 per cent moisture content, and that the surface of the piece reaches this point very quickly after drying starts. The interior of the piece, however, does not reach this point for a comparatively long time. Since green southern yellow pine lumber will normally shrink approximately 12 per cent in volume when dried completely, the potential capacity for unequal shrinkage between surface and interior during kiln drying is considerable.

Shrinkage in a piece of wood is for all practical purposes proportional to the amount of moisture lost below the fiber-saturation point. (Figs. 4 and 5 and p. 10.) For example, when a piece or any portion of a piece of southern yellow pine has reached 15 per cent moisture content approximately $\frac{25-15}{25}=10/25$ or two-fifths of the total shrinkage normally possible has occurred, and when it reaches 5 per cent moisture content the shrinkage is four-fifths of the total. Consequently the first step in establishing a drying schedule for green lumber is to select an initial humidity that will hold the moisture content at the surface of the lumber close to the fiber-saturation point, so that surface shrinkage will be temporarily retarded while evaporation may be at its highest permissible rate. On the other hand, in order to secure a flow to the surface of an amount of moisture sufficient to make a high rate of evaporation possible the surface must be below the fiber-saturation point far enough to cause transfusion of the moisture from the interior to it (p. 4). Then as the interior passes below the fiber-saturation point and continues to dry the kiln humidity is lowered by stages, so that the surface will be enough drier than the interior to permit drying but not enough to allow much difference in shrinkage.

DRYING CONDITIONS FOR KNOTTY STOCK

Clear, straight-grained stock when handled as just outlined may be dried to a very low moisture content practically without degrade. As explained on page 13, however, knots do not shrink with the wood surrounding them. Consequently knotty stock should not be dried to as low a moisture content as straight-grained, upper-grade material; since shrinkage is substantially in direct proportion to the drop in moisture content below the fiber-saturation point, the lower the moisture content the more probable will be damage to the knots. Further, the purposes for which knotty grades are used are ordinarily less exacting as to moisture content than those of the upper grades, and accordingly a moisture content equivalent to a well air-dried condition is generally considered quite satisfactory. The schedules made up for the knotty grades, therefore, are intended to prevent every possibility of overdrying, doing it through the use of relatively high humidities at all periods of drying, including the minimum humidity of the final period.

CRITICAL TEMPERATURE

All woods are more sensitive to temperature when green than when dry. A combination of heat and moisture at a temperature sufficiently high, continued over a considerable period, weakens the wood structure so much that it will yield to shrinkage stresses in the final stages of drying, thus making the occurrence of honeycombing and collapse very likely. The lowest temperature that will permit such a result is called the "critical temperature." For green material the critical temperature varies widely among species, generally being lower for hardwoods than for softwoods. As the stock becomes drier and drier the critical temperature for a given species becomes higher and higher. Thoroughly kiln-dried stock of any species can withstand a very high kiln temperature without the development of degrade. Drying schedules commonly recognize the critical temperature of the species concerned; the initial temperatures for green or semigreen stock are kept below the point where injury is likely to occur, and as the drying progresses the temperatures are increased. Furthermore, as stock increases in thickness the initial drying temperatures are lowered.

KILN SCHEDULES FOR SOUTHERN YELLOW PINE

In comparison with most species the critical temperature of southern yellow pine is quite high, permitting the use of relatively high initial kiln temperatures. The temperatures given in the following schedules are considered the most severe to which any part of the kiln charge should be subjected. These temperatures, together with the other conditions specified, are intended to dry the charge to an average moisture content of approximately 7 per cent for No. 1 Common and Better stock and approximately 10 per cent for lower-grade stock. The schedules, applying to the stock separations most common at southern pine mills, are for operation on a flat time basis and are intended for use with forced-circulation compartment kilns. (Tables 4 to 8, inclusive.) For natural-circulation compartment kilns the same dry-bulb temperature may be used, but the relative humidities must be about 10 per cent lower than the values given, since otherwise the period required for drying will be excessive.

TABLE 4.—*Kiln-drying Schedule 106 for southern yellow pine, intended primarily for fast-circulation compartment kilns*

[For 1 by 3 inch and 1 by 4 inch No. 2 Common and Better flooring and partition stock]

Time in kiln after which changes should be made	Dry-bulb temperature	Wet-bulb temperature	Relative humidity
Hours	*° F.*	*° F.*	*Per cent*
0	175	170	89
5	190	170	63
35	200	160	39
67	190	182	84
72		End of run	

TABLE 5.—*Kiln-drying Schedule 107 for southern yellow pine, intended primarily for fast-circulation compartment kilns*

[For 1 by 6 inch and wider No. 1 Common and Better lumber]

Time in kiln after which changes should be made	Dry-bulb temperature	Wet-bulb temperature	Relative humidity
Hours	*° F.*	*° F.*	*Per cent*
0	180	175	89
5	190	170	63
35	200	170	51
59	210	170	41
91	190	182	84
96		End of run	

TABLE 6.—*Kiln-drying Schedule 108 for southern yellow pine, intended primarily for fast-circulation compartment kilns*

[For 1 by 6 inch and wider No. 2 Common lumber]

Time in kiln after which changes should be made	Dry-bulb temperature	Wet-bulb temperature	Relative humidity
Hours	° *F.*	° *F.*	*Per cent*
0	175	170	89
5	190	170	63
35	200	[1] 170	51
67	190	182	84
72		End of run	

[1] For stock containing very large knots use a wet-bulb temperature of 177° F.

TABLE 7.—*Kiln-drying Schedule 109 for southern yellow pine, intended primarily for fast-circulation compartment kilns*

[For all widths of 5/4-inch and 6/4-inch finish stock]

Time in kiln after which changes should be made	Dry-bulb temperature	Wet-bulb temperature	Relative humidity
Hours	° *F.*	° *F.*	*Per cent*
0	175	170	89
5	180	170	79
10	190	170	63
35	200	170	51
85	200	160	39
115	190	182	84
120		End of run	

TABLE 8.—*Kiln-drying Schedule 110 for southern yellow pine, intended primarily for fast-circulation compartment kilns*

[For all widths of 8/4-inch finish stock]

Time in kiln after which changes should be made	Dry-bulb temperature	Wet-bulb temperature	Relative humidity
Hours	° *F.*	° *F.*	*Per cent*
0	175	170	89
5	180	170	79
10	190	170	63
50	200	170	51
108	200	160	39
138	190	182	84
144		End of run	

In progressive kilns, on the other hand, temperature and humidity conditions are more a matter of location in the kiln and less one of intentional change at stated intervals. Temperature control is usually limited to one end of the kiln, most frequently the dry end. In it both temperature and humidity may be maintained quite constant but at the green end the temperatures vary more or less, being lowest immediately after loading and rising gradually as the stock becomes drier. Each operator of a progressive kiln will have to work out compromise schedules that meet the conditions in his particular kiln. Probably the most satisfactory way to do this will be to control the dry end at the maximum temperature and the minimum humidity given in the proper schedule for compartment kilns. For example, to apply Schedule 107 to a progressive kiln, the dry-bulb temperature at the dry end would be 210° F., the wet-bulb 170°, and the relative humidity 41 per cent. The temperature at the green end would be the natural difference between the two ends and consequently it is very unlikely that this temperature would exceed 190° during the first 24 hours. The final 5-hour conditioning treatment specified in the schedules, of course, is impracticable in natural-circulation progressive kilns.

The time required for drying varies somewhat with the class of stock. The time given in the schedules is an average minimum period suitable for normal virgin-growth longleaf or shortleaf stock. Many operators will find it necessary to keep the stock in the kiln for 6 to 12 hours longer than the periods given. Second-growth shortleaf pine in the longleaf areas, and oldfield pine[12] in particular, is likely to require 25 per cent more time in the kiln, and the same is true of rapid-growth and dense-growth longleaf. When additional time is needed, the final drying period, which immediately precedes the conditioning treatment, may be extended as necessary.

FINAL CONDITIONING TREATMENT

The object of the final high-humidity conditioning treatment specified in the drying schedules is to relieve casehardening and to make the moisture content of the stock more nearly uniform; how this is accomplished will be described later. It is customary in conditioning treatments, especially with hardwoods, to employ temperatures 15° F. or more above the maximum drying temperatures in the schedule. The same method would be advocated for southern yellow pine if it were practicable. In the average kiln, however, it is difficult to maintain a wet-bulb temperature much above 180° without a tremendous steam consumption. On the other hand, it is equally difficult to cool the charge quickly from 200° or 210° to much less than 190°, because of the large amount of heat in the stock and in the kiln walls. To secure the comparatively small difference between dry-bulb and wet-bulb temperatures desired for such conditioning, therefore, in the preceding schedules each temperature is shifted a little way toward the other, thus accomplishing the purpose intended with a reasonable expenditure of steam and of time.

STOCK SEPARATION TO HASTEN SEASONING

If a kiln charge includes both fast-drying and slow-drying stock, it is the slow-drying material that determines the time required in the kiln. Results better than those possible with a mixed charge, better both in respect to quality of drying and in utilization of kiln space, can be secured through intelligent separation of stock. Ordinarily, sapwood in normal-growth southern yellow pine will require about 12 hours longer in the kiln than heartwood because it

[12] See footnote 8 on p. 15.

contains more moisture to be evaporated. Again, the No. 2 Common grades require less time than the upper grades because they are not dried to so low a moisture content. Further, some southern pine plants, which receive considerable quantities of red heart,[13] find that it can be dried in 30 to 36 hours less time than upper-grade stock. Considering the preceding factors, the stock separations should be about as follows: No. 1 Common and Better sapwood, No. 1 Common and Better heartwood, No. 2 Common and lower stock, and red heart. Further separations for thickness and for the characteristic differences between some kinds of longleaf and of oldfield [14] pine should be made as required.

MOISTURE-CONTENT DETERMINATION

OVEN-DRY METHOD

One of the primary requirements of successful drying is a means for the accurate determination of the moisture content of lumber. The customary method for such determination is to cross cut the piece to be tested at least 2 feet from one end, to avoid the effect of end drying, and then again about three-quarters of an inch from the first cut, thereby obtaining a cross section as wide and as thick as the original stock and three-quarters of an inch along the grain. All loose splinters are then removed from the section and it is weighed immediately on a sensitive scale. After recording the weight, which is called the original weight, the section is placed in a drying oven maintained at a constant temperature of about 212° F., and is left there until it has attained a practically constant weight, which will be in from 8 to 12 hours for kiln-dried southern yellow pine. It is then reweighed, to obtain the oven-dry weight. The difference between the original and the oven-dry weights represents the weight of the moisture originally in the section. The oven-dry weight represents the weight of actual wood substance with all water removed. The percentage of moisture content may now be determined by dividing the difference between the original and the oven-dry weights by the latter and multiplying the result by 100. The formula is:

$$\text{Moisture content based on oven-dry weight} = \frac{\text{Original weight} - \text{oven-dry weight}}{\text{Oven-dry weight}} \times 100.$$

As an example, if the original weight is 150 grams and the final weight is 90 grams, a difference of 60 grams, the moisture percentage will be $\frac{60 \text{ grams}}{90 \text{ grams}} \times 100 = 66.7$ per cent.

Although any system of weights may be used, the most common is the metric, the unit weight of which is the gram; fractions of a gram are expressed in decimals. Any suitable balance may be used. One of the most popular among kiln operators is a multiple-beam type: this balance has a pan suspended from the main beam, and each beam is provided with a sliding weight. It has a normal capacity of 111 grams, with an auxiliary loose weight that nearly

[13] See footnote 9 on p. 15.

[14] See footnote 8 on p. 15.

doubles this capacity. With ordinary metal bearings, the sensitivity of this balance is about 0.05 of a gram, and with agate bearings it is sensitive to about 0.02 of a gram. Balances can be obtained from most dry-kiln manufacturers and from dealers in scientific instruments.

INSTANTANEOUS METHODS

Since several hours are required to make a moisture determination by the oven-dry method [15] a quicker means for determining when the charge is ready to leave the kiln is desirable for a rapid-drying stock like southern yellow pine. The length of time that the stock has been in the kiln may be taken as an indication of when to begin making definite tests, but should not be considered proof that the lumber is suitably dry, since the drying period varies with many factors. The moisture content of a fresh charge may be either higher or lower than usual, the kiln may have been shut down for a few hours, the temperature in the kiln may have been below normal, chilled stock loaded on a cold winter day may take from 6 to 12 hours longer to dry than stock loaded on a moderately warm day, and sometimes an unusually large amount of sapwood is present. These and similar factors may either increase or decrease the time in the kiln, thus making a definite test imperative.

Some experienced kiln operators can test stock for dryness by cutting into the stock with a sharp knife, obtaining a splinter from the board and snapping it much the same as breaking a match stick. If the piece breaks freely and sharply it is dry, but if the piece appears tough and does not break apart readily it is still green. This knife test is usually applied to a number of sapwood boards scattered over the face of the pile and the examiner often judges as much by the way the knife cuts the stock as by the action of the splinter.

When southern yellow pine becomes overdry a strong, pungent odor escapes from the kiln. A few pieces in a kiln charge always dry more rapidly than the rest; for instance, a charge dried to an average moisture content of 5 or 6 per cent will contain some pieces of only 2 per cent. The 2 per cent pieces are overdried; their brittleness is increased, and something in the wood, possibly the oleoresin, evaporates, causing the pungent odor mentioned. Some operators become skillful in detecting an odor that precedes the one from overdry stock, and pull the load on this indication.

LIMITATIONS OF THE INSTANTANEOUS METHODS

Kiln runs should be checked frequently with a positive moisture determination, although termination of the run need not always be delayed for the outcome of the determination. Apparatus for making such determinations quickly are being developed; at present, however, the only positive method is the oven-dry. An operator skillful with the knife or other instantaneous test can become skillful and can remain so only through constant checking of his rule-of-thumb method. Further, the number of orders for which a moisture content is specified by the buyer is constantly increasing. The term "kiln dried" does not in itself determine how dry the stock may

[15] See footnote 4 on p. 2.

be nor does the knife test, the time in the kiln, or the odor. Only the equivalent of an oven-dry test will do that.

VARIATION IN MOISTURE CONTENT THROUGHOUT THE KILN CHARGE

At the time of unloading the kiln there is usually a rather wide difference in moisture content between the driest and the greenest pieces. The higher the average moisture content of the kiln charge the wider this difference is likely to be. It is less in stock dried in kilns having forced or augmented circulation and humidity control than in kilns depending upon natural circulation, with or without humidity control.

Tests have shown, where the average moisture content at the kiln door in 4/4-inch stock is about 8 per cent, that 90 per cent of the stock is below 12 per cent moisture content. In the remaining 10 per cent of the stock individual pieces containing between 20 and 30 per cent are sometimes found, although where good kiln control exists the upper limit ordinarily is below 18 per cent. Consequently tests on one or two boards will not be indicative of the true range of dryness of the charge; it is better to make several tests, 10 or more, when a fair degree of accuracy is desired.

The lowest moisture content in a truck load of stock is usually found in the outer layers of the pile and in the upper half of the load; the high values occur in the middle of the load and in the lower half. Further, there are differences in the stock itself, that from certain logs drying more slowly than the stock from others; this fact frequently accounts for lack of uniformity in the drying of adjacent boards. Pitchy stock, for instance, dries much more slowly than stock free from pitch. A piece of 4/4-inch stock showing heartwood full of pitch in the center of the cross section and pitch-free sapwood on the outside was found to contain 31 per cent moisture in the heartwood and 109 per cent in the sapwood before it entered the kiln. When the load was removed from the kiln this piece was again tested; the heartwood was found to contain about 17 per cent and the sapwood only 8.4 per cent moisture.

EFFECT OF THE DRYING SCHEDULE ON THE EXUDATION OF PITCH

Injuries to the growing southern yellow pine tree will cause pitch to accumulate in the surrounding wood fibers, and large injuries, such as turpentining, sometimes cause pitch deposits that permeate the wood for a considerable distance above the wound. This pitchy material becomes partially fluid when subjected to the temperatures usual in the kiln and moves to the surfaces of the pieces. The lighter oils will then evaporate and the residue will remain on the surfaces as rosin.

Degrade from pitch in southern yellow pine is most common where the stock is overdried and particularly where temperatures in excess of 220° F. are used. The lower the average moisture content of a kiln dried piece the greater the amount of pitch visible. Stock dried under schedules that prevent overdrying, by using relative humidities of not less than 40 per cent and temperatures not over 220°, has fewer pitchy pieces than stock dried where these conditions are exceeded. Where the moisture content of the stock is 5 per cent or more there is less pitch exudation than in stock ranging from 2 to 4 per cent. Apparently the resinous deposit does not move through the wood readily until most of the water has been evaporated.

COST OF SHUTTING DOWN THE KILN

At many plants the steam supply to the kiln is shut off from Saturday evening to Monday morning in order to conserve fuel. This may be done because of lack of storage space for fuel or because all surplus fuel is sold. Whatever the reason, the practice is bad, both for the lumber in the kiln and for the kiln structure. It is particularly bad practice in natural-circulation progressive kilns because of the manner in which it breaks up the continuity of the drying operation. Some tests were made in a battery of such kilns, the stock under observation being 4/4-inch No. 1 Common and Better longleaf pine drying under a 3-day schedule through the kiln. The degrade in stock unloaded Monday, Tuesday, and Wednesday was about double that of stock unloaded Thursday, Friday, and Saturday.

When the steam supply was cut off, on a Saturday, the temperature in the kilns dropped slowly; it was 24 hours before the temperature at the dry end dropped from 220° to 150° F. and 30 hours before it dropped to 120°, because of the heat stored in the walls and in the lumber. Such circulation as existed was crosswise instead of lengthwise because the walls were the principal source of heat. The humidity, on the other hand, dropped very rapidly throughout the kiln, particularly at the green end. Hence a considerable amount of drying, especially at the green end, took place while the steam was cut off. Late Sunday night, when the steam was turned on again, the stock in the green end had become so dry that the evaporation was no longer enough faster than at the dry end to reestablish the longitudinal circulation definitely and consequently the kiln operated temporarily as a compartment kiln. On Monday morning, the charge at the dry end was unloaded and a fresh load of green stock was placed in the kiln, after which the proper circulation reestablished itself. All of the stock in the kiln during the time the steam was cut off was overdried and accordingly sustained more kiln damage than the stock dried by continuous operation. A rough but conservative estimate of the degrade resulting from the Sunday-closing practice showed a loss of more than $450 in the value of the stock contained in eight kilns; to-day the loss would be greater.

The Sunday-closing practice also causes very rapid deterioration of the structure and the heating system. The alternate expansion and contraction in the brick walls of the kilns examined had produced great cracks, and the walls were out of line. Repairing, done presumably when parts of the wall had been found unsafe, was evident. The reinforced concrete roof was cracked and was slowly disintegrating at the cracks. The heating coils were in constant need of attention because of the effects of continued expansion and contraction. When it is necessary that the steam supply be cut off from a kiln, every effort should be made to maintain both the temperature and the humidity until the steam is again turned on. The dampers, both inlet and outlet, should be closed and if it is available a small amount of steam should be released from the sprays to retain the humidity.

STEAM CONSUMPTION

A tremendous amount of moisture escapes from the kilns every hour in the form of vapor. This vapor includes both the evaporated moisture and any steam used for humidification. The evaporated moisture alone averages approximately 25 pounds an hour for each thousand feet of ordinary lumber in the kiln, which is 1,312 pounds per hour for a 105-foot kiln holding 15 trucks of 3,500 board feet each. During some tests in a forced-circulation kiln on 4/4-inch No. 1 Common and Better longleaf pine the steam consumption averaged 2.76 pounds per pound of water evaporated, about one-half of which was used in maintaining humidity. For No. 2 Common stock, which had a faster average drying rate because of its shorter time in the kiln, the steam consumption was 2.16 pounds per pound of water evaporated. In natural-circulation kilns without humidity control, steam consumption is nearer 2 pounds per pound of evaporated water for No. 1 Common and Better and somewhat less for No. 2 Common stock. If kilns could be made reasonably vapor tight the amount of steam required could be reduced, particularly that required for controlling the humidity; in fact, if the kiln were practically vapor tight enough of the evaporated moisture could be retained to maintain the desired humidity, and the excess would then be allowed to escape through ventilators.

A change in the outside temperature has some effect on the steam consumption in dry kilns. A sharp drop, like that which at times occurs during a thundershower, shows an appreciable increase in such consumption. The peak load in progressive kilns occurs immediately after the kiln has been freshly charged and gradually decreases as the drying progresses. The same is true of compartment kilns, with smaller peaks occurring each time the temperatures are stepped up. In a natural-circulation progressive kiln under test, the average steam consumption was 1,091 pounds per hour; the peak load, which occurred immediately after loading, was 1,720 pounds per hour, and the minimum was 930 pounds per hour, just before unloading.

The amount of condensation per square foot of radiating surface is largely a matter of circulation. In adjacent kilns, one natural circulation and the other forced circulation, it was found that 1.08 pounds of steam could be condensed per square foot of radiating surface per hour in the forced-circulation kiln against 0.39 pound in the natural-circulation one. Where the efficiency of the heating coils is increased by good circulation, the amount of heating surface can be reduced proportionally.

TEMPERATURE-CONTROL DEVICES

CONTROL EQUIPMENT IN THE STEAM LINES

The desirability of controlling temperature and humidity has been discussed elsewhere. (Pp. 38 to 41.) The usual methods of controlling humidity require that the temperature also be controlled within reasonably close limits. The high temperatures used for drying southern yellow pine require high-pressure steam, exhaust steam not being hot enough to maintain the maximum temperature. Usually the steam supply is taken direct from the boilers to the kiln but, since the boiler pressure may vary widely because of the intermittent peak loads of the engines and other steam-operated machinery, a pressure regulator should be installed on the steam main to the kilns, preferably at or near the kilns. This pressure regulator should be set to provide from 80 to 100 pounds pressure in the steam main. The steam supply line to the coils in each kiln is provided with a globe or a gate valve by which the entire steam supply to each kiln may be turned on or cut off. Many kilns are provided with multiple coils, in which event each coil should be provided with an individual valve on its particular supply line, in addition to the main valves. All valves should be outside of the kiln in an accessible position, preferably in an operating pit below the tracks on the kiln platform.

MANUAL CONTROL

In the older types of kilns, the only control of temperature is through the hand-operated steam-supply valve on each kiln. Hand control in high-temperature kilns can hardly be expected to function within a 15° F. temperature fluctuation, and the variation is frequently 20° to 25°. Automatic temperature-control devices have become very popular in recent years and their use is spreading rapidly.

SELF-CONTAINED AUTOMATIC CONTROLLERS

Automatic temperature controllers, which are also called thermostats, are of two general types, the self-contained and the auxiliary-operated. The self-contained type consists of a bulb to be located in the kiln, a capillary tube connecting the bulb with the motor head of the valve, and the valve itself. The bulb and its connecting tube are filled with a suitable liquid or vapor that expands and contracts respectively with rise and fall of the kiln temperature, causing corresponding changes in pressure in the motor head, which in turn transforms the changes into motion. The movement of the motor head is transmitted through a stem to the valve. Self-contained thermostats, which are set for the temperature desired by means of a spring or sliding weights, are designed for a maximum range in temperature control of about 80° F. For example, if the range in temperature control is from 140° to 220°, the controller will not operate satisfactorily below 140° or above 220°. Since a material change in temperature of the motor head affects its setting, self-contained thermostats should not be placed where the temperature of the motor head approaches the temperature of the kiln, but should be located in a protected place where temperatures are reasonably constant, and of course lower than the kiln temperature; such a place preferably will be an operating pit below the kiln platform.

The principal field of usefulness of the self-contained thermostat is in progressive kilns, where the temperature at the control bulb is intended to be constant, rather than in compartment kilns, where temperatures are changed currently as required by the schedule.

AUXILIARY-OPERATED AUTOMATIC CONTROLLERS

Auxiliary-operated thermostats for dry-kiln use are made in various types; compressed air, electricity, water, or steam may be employed to operate the valve. The most common are the air-operated type, working under about 15 pounds gauge pressure. As with the self-contained type, the temperature-sensitive element, called a bulb, is located in the kiln and is connected by means of a capillary tube to the valve-operating mechanism outside of the kiln. Temperature changes at the bulb vary the pressure of the liquid or vapor within the bulb and the pressure changes are transmitted to the operating mechanism and then are relayed to a diaphragm-motor valve on the steam supply line; all auxiliary-operated thermostats, except the electrical, require a diaphragm type of motor.

The design of auxiliary-operated thermostats permits their operation through a very wide temperature range. Air-operated thermostats are provided with a pair of small pressure gauges, located on the air lines so as to show the position of the valve, which are of considerable assistance when the operator is making temperature adjustments. This type of thermostat is also manufactured in combination with a recording thermometer in which temperature adjustments are made by a direct-set arm on the face of the recorder chart.

HUMIDITY-CONTROL DEVICES

Humidity control is obtained by means of the same types of thermostats as those used for temperature control. The bulb in the kiln, however, is covered with a wick dipping in water or is kept moist by other means, so that evaporation at this bulb reduces its temperature (the wet-bulb temperature) below that of the kiln (the dry-bulb temperature). The reduction is proportional to the rate of evaporation, which in turn is inversely proportional to the humidity in the kiln when the circulation past the bulb is sufficient to enable it to give an accurate indication. The thermostat valve that is controlled by the wet-bulb temperature itself governs the steam supply to the sprays, admitting steam when the wet-bulb temperature drops, and closing the line as soon as the steam has raised the humidity to the value corresponding to the (wet-bulb) temperature for which the thermostat is set.

RECORDING THERMOMETERS

The temperatures and humidities within southern pine kilns are such that it is impractical to obtain temperature readings with ordinary indicating thermometers and hygrometers. Further, such readings are of value only in showing the temperature at the moment the reading is made. Recording thermometers for recording both dry-bulb and wet-bulb temperatures are very generally used and in consequence need no description here;[16] it is enough to say that good, reliable recording thermometers should be part of the equipment of every kiln where any degree of temperature or humidity control is attempted.

[16] See footnote 1 on p. 2.

LOCATION OF THERMOSTATS AND THERMOSTAT BULBS

Drying schedules are intended to specify the most severe conditions to which the lumber will be exposed during the stage of drying indicated. The most severe drying conditions obtain where the air enters the pile, which in natural-circulation progressive kilns is usually the bottom of the pile at the dry end of the kiln. If the bulb could be located between the heating coils and the lumber, accurate control would be reasonably assured. That position, however, is frequently impractical, and the next best place is usually on the side wall, possibly 20 feet back from the doors at the dry end. In natural-circulation compartment kilns having their characteristic air movement across the kiln, the side wall is again the best position. In forced-circulation kilns it is worth considerable thought and effort to find some means of locating the bulbs in the entering-air position, wherever it may be.

The temperature recorder will often show a wide fluctuation in temperature even with a controller in service in the kiln. Such a fluctuation was observed in a cross-piled compartment kiln where the circulation was supposed to be augmented by steam sprays, but was not so augmented because the sprays had been improperly located in the original installation. The heating coils consisted of one big unit below the rails, and the sprays were just above the coils, pointing upward; the bulb of the controlling thermostat was on a side wall. When the stock was green the circulation was downward from the lumber in spite of the spray, and up the side walls. After the temperature at the bulb had become low enough to open the thermostat governing the supply to the heating coils, some time would elapse before the air movement would carry the now rising temperature up to the bulb. When the bulb temperature reached the point at which the thermostat closed, the hot air moving from the coils to the bulb would still be increasing in temperature. The thermostat was actually opening and closing the steam supply line in accordance with its setting, but because of the slow air movement the temperatures coasted after the thermostat had functioned. In cases like this one the more rapid the circulation the less the variation in temperature. Furthermore, multiple heating units are also of advantage in that with them only a slight excess of heating surface is in use at any time and consequently the coils contain steam at all times, the thermostat acting only to throttle the excess steam.

HANDLING STOCK BEFORE AND AFTER KILN DRYING

PILING ON KILN CARS

Careful and proper stacking of the lumber on the kiln cars is a primary factor in successful kiln drying, practically equal in importance to proper kiln operation. Faulty stacking is more or less directly responsible for all of the warping and most of the end checking that occur in the kiln; it contributes to unequal drying and is the indirect cause of most of the splitting at the planer. Very few instances have been found in the southern pine region where the stacking approaches the standards required to keep at a minimum the degrade caused by this factor. Poor stacking is more a matter of carelessness and lack of appreciation of its importance than a matter of economy in stacking costs, for the standards of stacking discussed hereafter add almost nothing to the labor and only little to the number of stickers, crossties, and kiln trucks, and on the other hand offer several decided economies.

METHODS OF PILING

The plant layout usually determines whether the kiln trucks will be piled with the lumber crosswise (pl. 3, C) or lengthwise (pl. 3, A and B) of the kiln: the crosswise method, however, is the more common. Two styles of stacking are also used; flat stacking, in which the boards are laid flat on the trucks and the stickers are horizontal; and edge stacking, in which the boards stand on edge on the truck with the stickers vertical in the load. Edge stacking in southern pine mills is usually combined with cross piling. Flat stacking is more common than edge stacking.

REDUCING WARP[17]

It is a characteristic of lumber to tend to warp somewhat while drying; the amount of actual warp depends on the species of wood and on such factors as crookedness of grain, the presence of sapwood and heartwood in the same piece, and the position of the piece in the log, and most of all on the lack of restraint while drying. (Pl. 4.) Further, heat softens wood to some extent, making it less resistant to the internal forces that cause warping and also to any external forces to which the wood may be subjected. Fortunately the softening process reduces the magnitude of the internal stresses at the same time, and thus makes it possible to apply external forces advantageously. The sticker furnishes the external force, resisting the warp and holding the stock flat for a certain distance on each side. The greater the distance between stickers, the greater the amount of warp, and therefore the stickers must be spaced closely enough to hold the warp to a minimum.

The restraint that is exerted by the stickers, of course, comes largely from the weight of the lumber above them. Consequently the lumber in the extreme upper courses, which is restrained only lightly unless weights are placed on the pile, is likely to warp.

REDUCING CHECKING AND SPLITTING

Proper stacking will prevent a large part of the waste caused by end checks and splits. End checks that develop during drying will almost always stop at the first sticker they reach. Obviously the proper place for the end stickers is as near the ends of the load as possible. Splits that occur at the planer are principally a result of warp and may be reduced in proportion to the reduction of warp. In one test on southern yellow pine it was found that the waste resulting from trimming to hold the stock on grade was 0.7 per cent when the stickers were at the ends of the load and 2.5 per cent when they were back 6 to 12 inches from the ends. Warp may arise from

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[17] Warp is any variation from a true or plane surface. It includes crook, bow, cup, and twist, or any combination of these.

imperfectly manufactured stock, or from placing stock of unequal thickness in the same course; under such conditions the stickers have to bridge over the thin stock unsupported. The weight of the stock above will then bend or break the sticker and will thus cause distortion in the upper courses.

GOOD PILING PRACTICE

The limitations of edge piling are such that it is more or less impractical to conform to all of the essentials of good piling when employing the edge method. The following discussion, therefore, is predicated on flat piling although some of the features may be followed in edge piling. The essentials of good piling are (1) a sufficient number of strong kiln trucks in good condition; (2) rigid supports under each line of stickers; (3) stickers of sound, clear material of even thickness and with proper spacing, placing in vertical alignment in the car over the supports; (4) stickers at the extreme ends of the load; and (5) uniform thicknesses of stock in each course.

For end piling either the sticker spacing or the transfer track will determine the location of the kiln trucks; an extra pair of trucks may be required to support the crossties needed in the middle of the tram. (Pl. 3, B.) For cross-piled trucks, steel rails or I beams are commonly used under the pile; a reasonable number of them provide a rigid support for the stickers regardless of sticker spacing.

BOX PILING

Where stock on a car is of mixed lengths, it should be box piled, with the long lengths on the outside of the pile and the short lengths inside and so placed that one end of each board is on the outside sticker at one end of the car, and with successive short boards in the same course extending to opposite ends. In each succeeding course the outer ends of the short boards should be kept immediately over the ends of those below in order to furnish support for those above.

SPACE FOR VERTICAL CIRCULATION IN FLAT PILING

For natural-circulation and combination natural-circulation and forced-circulation kilns in which the principal air movement is vertical, ample space should be left between adjacent flat-piled boards or groups of boards in each course in order to provide a free movement of the air. Such spaces in successive courses should be in vertical alignment so as to form unobstructed air passages (flues) from the top to the bottom of the pile. These flues should be not less than 4 inches wide, and if the circulation is feeble or if the drying is not substantially uniform throughout the kiln charge the width should be increased, up to a maximum of 6 inches. The distance between flues should not exceed 14 inches, and 12 inches is better; the smaller distance may be obtained by grouping three 4-inch boards, two 6-inch boards, one 4-inch and one 8-inch, and so on.

STICKERS

The stickers should be made of clear, straight-grained stock, entirely free from both stain and decay, and should be dressed to a uniform thickness of not less than seven-eighths inch for flat-stacked piles. If the stickers are made about one and one-half times as wide as they are thick they will lie flat instead of tending to roll when the boards are laid upon them. Sometimes stickers 3 to 4 inches wide are used but this is poor practice because such stickers cover so much surface that the drying is unequal and checks are likely to develop in the lumber underneath them. (Pl. 5.)

In edge stacking the size and the requirements of the stacking machine may determine both the width and the thickness of the stickers.

The stacking racks and machines used for edge piling in the South usually limit the stickers to three rows in the length of the pile; the flow of air is through the spaces between stickers. The kiln trucks ordinarily are not provided with an automatic take-up device of sufficient capacity and hence it is quite common, when the lumber is partly dried and shrinkage has begun, for layers or parts of layers to fall between stickers, thus closing up some of the air passages. (Pl. 6.)

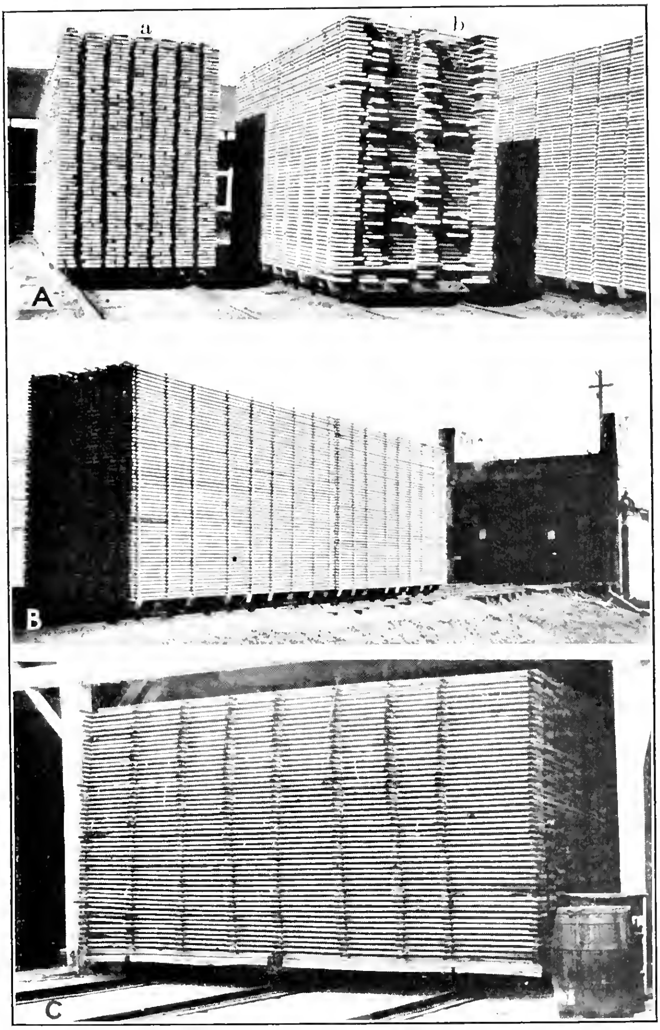
LOSS CAUSED BY IMPROPER STICKERING

Numerous tests have been made to demonstrate the advantage of proper piling for No. 2 Common and Better stock. The results of some of these tests follow. A 16-foot load of longleaf pine, 6-inch and wider, No. 2 Common and Better, piled with six stickers varying in spacing from 2 feet 6 inches to 4 feet 8 inches, with the sticker lines placed over crossties, was compared with a load of similar stock having stickers 2 feet apart. The stock was dried in a progressive natural-circulation kiln without temperature or humidity control, and was run through the planer and graded about 24 hours after leaving the kiln. Table 9 shows the average depreciation in value per thousand board feet of each load.

TABLE 9.—*Comparison of losses caused by degrade, for kiln drying under conditions differing only in the spacing of the stickers, in 6-inch and wider longleaf pine lumber 6, 8, 10, and 12 feet long*

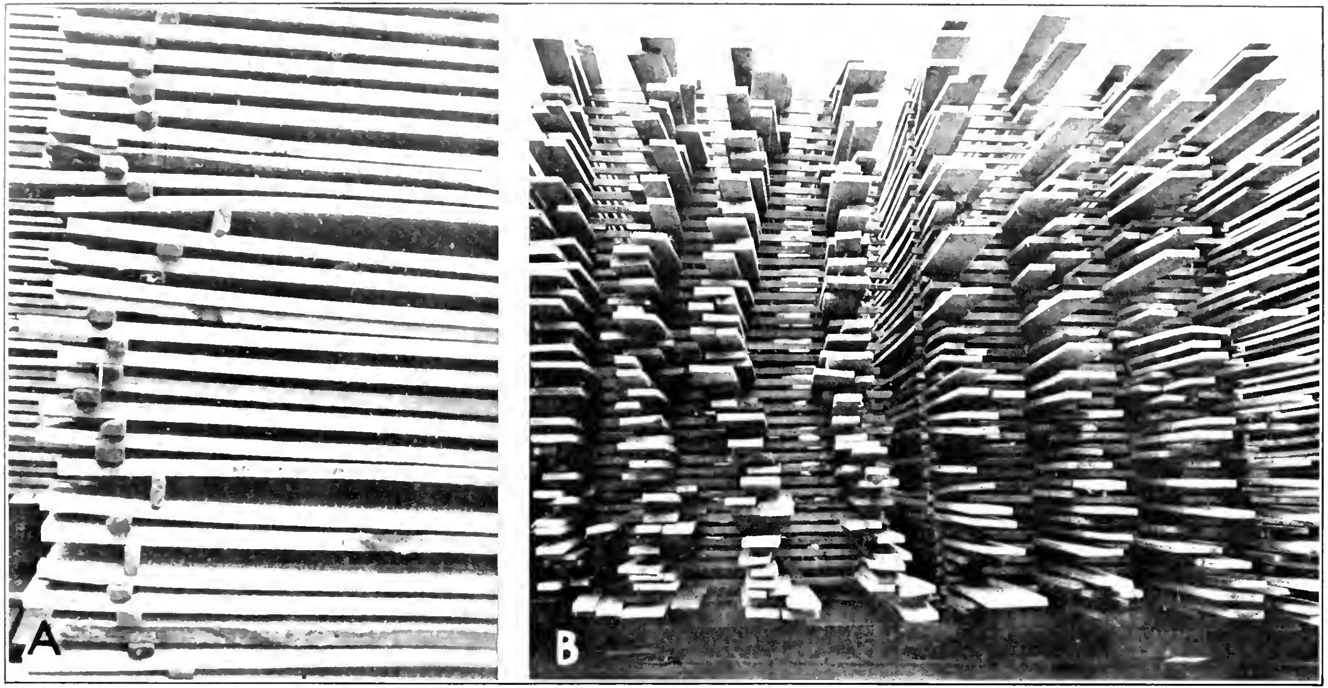
Grade of stock	Losses caused by degrade when using—			
	Six sticker tiers spaced from 2 feet 6 inches to 4 feet 8 inches		Sticker tiers 2 feet apart	
	Stock on grade	Loss per 1,000 board feet [1]	Stock on grade	Loss per 1,000 board feet [1]
	Per cent	*Dollars*	*Per cent*	*Dollars*
B and Better	85.7	5.90	90.8	3.37
No. 1 Common	68.6	9.08	77.7	5.74
No. 2 Common	58.3	1.59	62.0	1.23

[1] Based on lumber prices substantially the same as those for January, 1929.



M—11472-F; M—987-F

Flat end-piled truck loads of southern yellow pine are shown in A and B. In A–*a*, the number of sticker tiers is sufficient, each tier of stickers is supported by a tie direclty under it, all of the boards in each course are of the same thickness, the narrow boards are grouped in pairs, and the sides and the ends of the pile are uniform and vertical, all of which is highly desirable. On the other hand, placing the outer stickers at the extreme ends of the boards would reduce both warping and end checking, and uniformity of the vertical air channels through the pile would give faster and more even drying. Box piling is illustrated in A–*b;* the short lengths are inside the outer tiers of full-length boards and are staggered from end to end of the pile. Although box piling in itself is excellent practice, the vertical air channel at the left of the pile illustrated is either fully closed or badly obstructed at several points; such nonuniformity causes slow and uneven drying. The two loads shown in B are piled even better than those in A. In addition to showing good piling in general, these loads illustrate the use of three pairs of trucks under a single load; each three pairs of crossties are supported on a pair of trucks. The general features of the flat cross piling of southern yellow pine in C are excellent. The five courses of common lumber piled solid for the support of the load, however, are an expensive practice because of poor seasoning and excessive degrade in the pieces used, extra handling, and also because of the deformation they permit in the lumber they are supposed to sustain. Pile supports of steel **I** beams or rails pay for themselves in a short time; even boiler tubes selected from discards may be used to advantage.

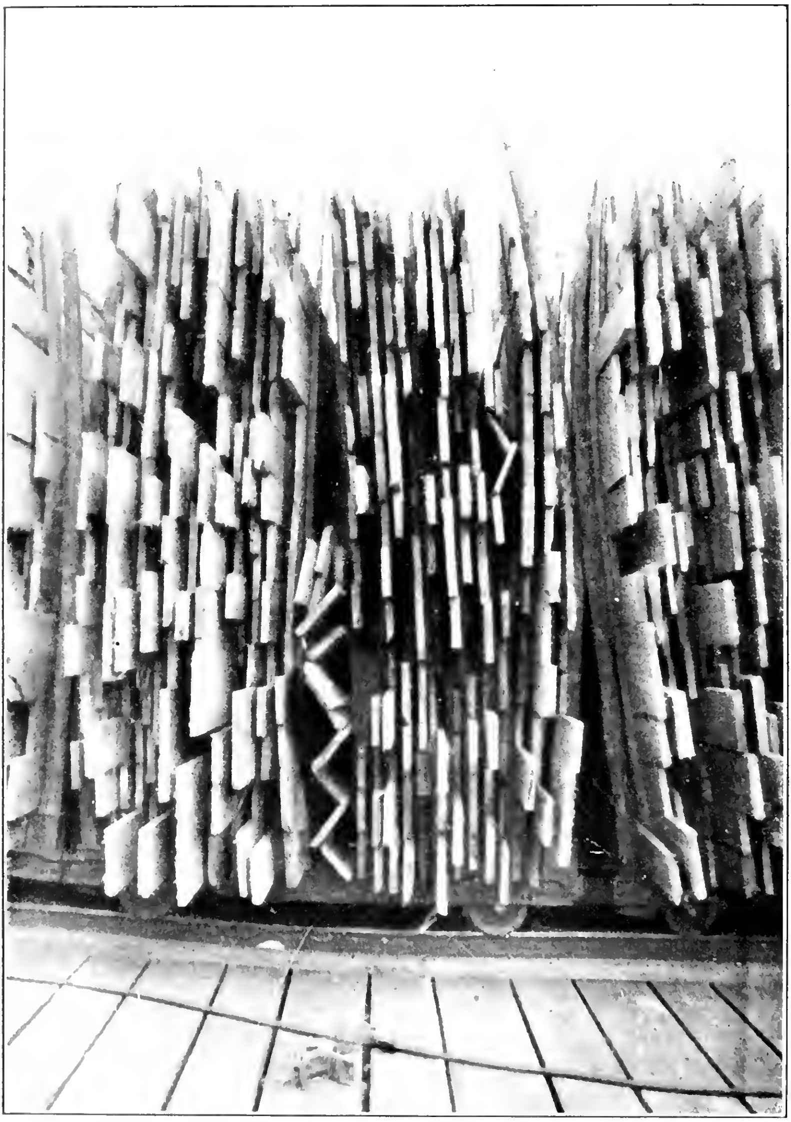


M—2305—F; M—5612—F

A.—An example of particularly bad stickering. The vertical misalignment of the stickers causes bowing of the boards. Further, the inequality of the spaces between courses will certainly cause unequal drying and may cause degrade. B.—Three tiers of stickers, even though in good vertical alignment, have failed to provide sufficient support in these truck loads and consequently the stock is badly bowed and twisted, and some crook is evident; the overhanging ends made matters worse. The excessively wide flues in the piles sacrifice kiln capacity and tend to produce overdrying in some parts of the stock, while the nonuniformity of the same air channels certainly causes uneven drying; some flues are badly obstructed by the poorly piled boards

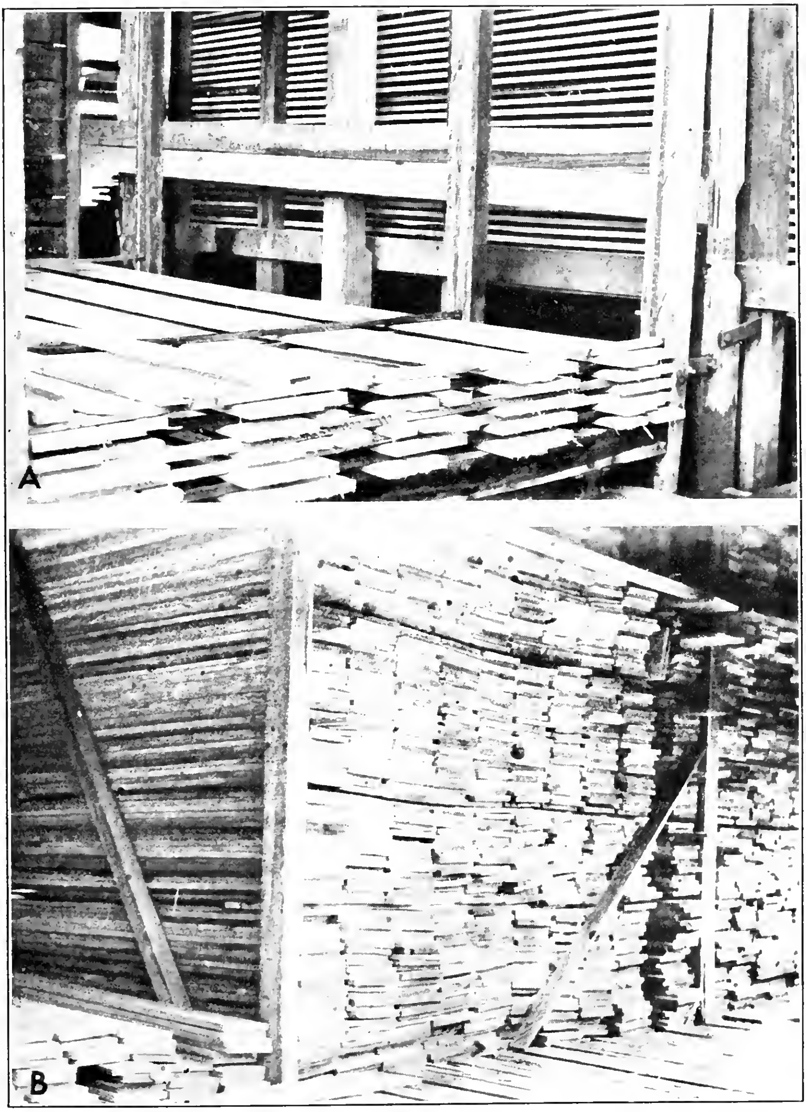
M—2289—F

A check in 1 by 6 inch lumber resulting from the uneven drying caused by an excessively wide sticker. Narrow stickers, from 1¼ to 2 inches in width, permit better drying of the wood they cover



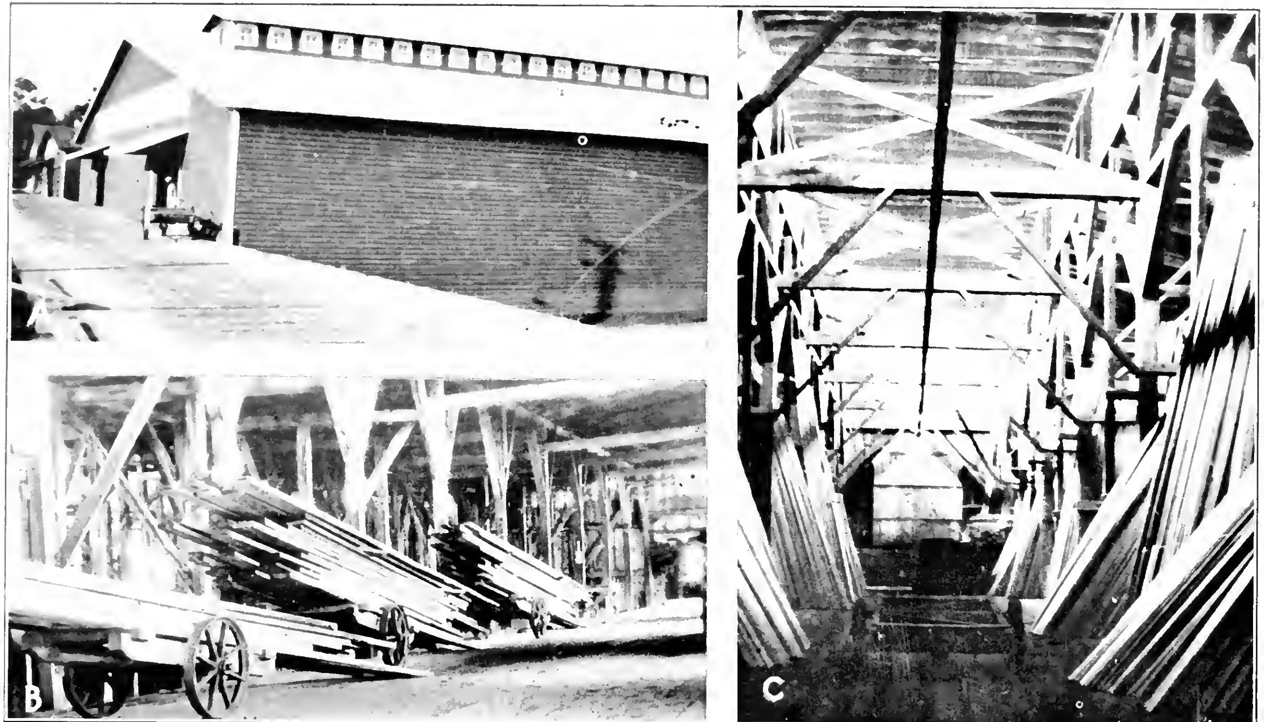
M—3003—F

Edge-stacked lumber with tumbled tiers as a result of carelessness at the time of stacking. The position of the lumber causes poor drying in such tiers and often causes severe checking also. Shrinkage during drying sometimes results in tumbling as bad as this, especially when automatic take-up devices are not used or are inadequate



M—2803—F; M—5611—F

A.—Sticker guides for stacking southern yellow pine lumber for kiln drying. The use of such guides is good practice, since it reduces both piling costs and kiln degrade, but enough guides should be provided for all the tiers of stickers that the stack needs. B.—Upper-grade kiln-dried lumber bulk piled in a rough dry shed. The careless piling in the courses about 3 feet from the floor is likely to cause splitting. Proper bulk piling for periods of three weeks or more is beneficial to warped and unequally dried stock and also to casehardened stock



M—11561—F

An inclosed shed suitable for the storage of stock both before and after machining. The humidity within such sheds is normally lower than that in open sheds and consequently the moisture content of stock in inclosed sheds will average lower than that in open sheds. A.—An exterior view. B.—Kiln-dried rough stock on buggies ready for the planing mill. C.—The usual method of storing dressed southern yellow pine. Stock standing on end has less surface covered by adjacent boards than bulk-piled stock and consequently reacts more quickly to the atmospheric conditions in the finish shed

In another test on longleaf pine only four sticker tiers, placed 4 feet apart with the stock overhanging 2 feet at each end, were used; this is a method of piling very common at many southern pine mills. Kiln cars so loaded were dried along with some 9-sticker loads in kilns having forced circulation, accurate temperature and humidity control, and a drying schedule similar to those recommended in this publication. Here again all the stock was run through the planer the day following its removal from the kiln, and was graded and tallied behind the planer. The average depreciation in value per thousand board feet appears in Table 10. A similar test was made on 8-inch No. 2 Common shortleaf pine in a typical progressive kiln. The depreciation in value of this stock appears in Table 11.

Table 10.—*Comparison of losses caused by degrade in 4-sticker and 9-sticker piles of 8-inch upper-grade longleaf pine*

Grade of stock	Loss caused by degrade when using—			
	4 stickers per course		9 stickers per course	
	Stock on grade	Loss per 1,000 board feet [1]	Stock on grade	Loss per 1,000 board feet [1]
	Per cent	*Dollars*	*Per cent*	*Dollars*
B and Better, S4S	73.30	3.69	97.19	0.60
No. 1 Common, S4S	84.40	3.17	97.95	.64

[1] Based on lumber prices substantially the same as those for January, 1929.

Table 11.—*Comparison of losses caused by degrade in 4-sticker and 9-sticker piles of 8-inch No. 2 Common shortleaf pine*

Run No.	Loss caused by degrade when using—			
	4 stickers per course		9 stickers per course	
	Stock on grade	Loss per 1,000 board feet [1]	Stock on grade	Loss per 1,000 board feet [1]
	Per cent	*Dollars*	*Per cent*	*Dollars*
	69.0	1.72	78.8	1.16
	83.7	.93	91.0	.51
	82.4	.98	85.4	.81

[1] Based on lumber prices substantially the same as those for January, 1929.

Very slight cupping will cause dry southern yellow pine stock to split as the stock is flattened on the planer bed, and will also increase the breakage and the loosening of knots. The support given to the stock by suitable stickers spaced about 2 feet apart almost entirely prevents distortion during drying. In the test, crook was found to be very common in the 4-sticker stock, particularly slight and medium crook, which in itself was not severe enough to cause degrade. In the 9-sticker lots there was almost no crook, although what was found was pronounced and usually was enough to cause degrade. The tests have shown that the close sticker spacing prevents most of the crook, particularly the slight and medium, but where very pronounced compression wood occurs on the edge of the piece crook develops in spite of the restraint of the stickers.

COMPARISON OF FLAT AND EDGE STACKING

While flat stacking is the rule at the majority of the southern pine mills (pl. 7, A), the possibility of using mechanical stacking and unstacking equipment has induced some mills to adopt edge stacking in the expectation of a reduction in labor costs. Edge-stacked lumber, however, is more free to warp in drying and consequently the degrade from planer splitting is increased proportionately. Three tests were made at one mill cutting shortleaf pine, in which one car each of edge-stacked and of flat-stacked lumber was put through the same kiln at the same time, with the results shown in Table 12.

TABLE 12.—*Comparison of losses caused by degrade in edge-stacked and in flat-stacked 1 by 8 inch No. 2 Common shortleaf pine*

Run No.	Loss caused by degrade in lumber—			
	Edge-stacked, using 3 tiers of stickers		Flat-stacked, using 9 tiers of stickers	
	Stock on grade	Loss per 1,000 board feet [1]	Stock on grade	Loss per 1,000 board feet [1]
	Per cent	*Dollars*	*Per cent*	*Dollars*
1	61.6	2.09	78.8	1.16
2	57.6	2.34	85.4	.81
3	84.4	.85	97.6	.13

[1] Based on lumber prices substantially the same as those for January, 1929.

The tests of Table 12 were made in progressive natural-circulation kilns in which the temperature was under automatic control. In run 3 the humidity was automatically controlled as well and the steam sprays were so installed as to augment the natural circulation; overdrying was prevented by using proper final humidities. It is quite apparent from these tests that, whether southern yellow pine is dried with or without suitable humidity control, flat-stacked stock piled with numerous rows of stickers gives the better results.

STORAGE AFTER KILN DRYING AND BEFORE MACHINING

It has been pointed out that there are three major independent factors in seasoning stock in preparation for planing, two of which—kiln operation and stacking for the kiln—have been examined. The importance of the third—storage of kiln-dried rough stock in dry shed (pls. 7 B and 8)—depends largely upon the conditions maintained in the kiln. The discussion following deals only with the effect of storage on kiln degrade; it is not concerned with the other purposes and with the general advantages of the practice of dry storage.

The moisture content of stock at the time of machining has a very important bearing upon degrade. If the stock is overdry, the tongues, grooves, and beads tear and break and the plain surfaces chip. Such stock also splits and checks badly, and any cup or twist greatly increases the damage. Underdry stock does not plane smoothly. Stock as it leaves the kiln often varies widely in moisture content, particularly with natural-circulation kilns, some pieces as low as 2 per cent moisture content and other as high as 20 per cent or more coming from the same kiln charge of upper-grade stock. When stored in bulk the tendency is for all pieces to come to a moisture content in equilibrium with the atmosphere. When stock is piled solid, the pieces of high-moisture content transfer moisture to those of low-moisture content, and the pile, as a whole, gradually and slowly attempts to reach the equilibrium moisture content. The exposed, overhanging ends will rapidly reach this condition, but within the pile several weeks or even months may elapse before the moisture content is equalized. Narrow flooring strips will come to equilibrium more rapidly than wide boards, since the percentage of free air space and the resulting ventilation within the pile is greater for the strips.

In an average dry shed, so constructed as to protect the stock from driving rains, the equilibrium moisture content of the stock as found by tests made on overhanging ends will range from 8 to 12 per cent, depending upon the time of year and the outside atmospheric conditions. Ordinarily the shed conditions are such that all the stock will have a lower moisture content than the same material would have if it were stored in piles in the open. Further, the moisture content of stock within the piles will usually be lower than that in the overhanging ends. In some tests made on longleaf flooring strips in storage three weeks the overhanging ends showed a moisture content of 10.5 to 11.5 per cent, while the portions of the same pieces within the pile contained only from 6.5 to 9 per cent moisture.

The atmospheric conditions within unheated sheds are actually such that the equilibrium moisture content of lumber stored in them may attain a value above that desired for upper-grade stock, but the rate of absorption in bulk piles is quite slow and a considerable period of time elapses before the interior of a fresh pile is affected. On the other hand, if the moisture content at the ends of the piles, especially that of the projecting portions of overhanging ends, varies from the moisture content of the portion of the board within the pile some distortion in shape will follow after machining. For example, flooring strips such as those already described may contain at the time of machining about 11 per cent moisture throughout 2 or more feet at one end where the end overhung the main portion of the pile, and perhaps 6 per cent throughout the rest of the strip. Later, after the moisture content has become uniform throughout the length of the machined piece, the dimensions will not be the same in the end section as in the rest of the piece. Stock in this condition is sometimes found in the finish shed before shipment and very frequently is found at the retail yards or after delivery to the building where it is to be used.

Overhanging ends obviously should be avoided in so far as possible. Further, where assurance of moisture control for the lumber in storage is desired, the sheds should be inclosed on all sides and provided with a heating system for use in cold or damp weather.

Casehardening stresses are relieved to some degree by the slight gradual changes in moisture content of stored stock, as it follows slowly the variation in atmospheric humidity. In this respect the action is quite similar to that obtained by means of the steaming process called for in the drying schedules, but the results are less positive and by comparison are very slow. Casehardening tests on longleaf pine flooring strips that had been dried in a natural-circulation progressive kiln and stored three weeks indicated that there was very little stress present, but the same kind of stock as it left the kiln was quite severely casehardened. Twist, bow, and cup are to some extent ironed out in storage under the weight of the pile.

Bulk piling, however, does not particularly affect the degrade caused by knots. In a test on 8-inch No. 2 Common longleaf somewhat overdried in a progressive natural-circulation kiln, the degrade when the stock was run direct from the kiln to the planer was 53.8 per cent, but after bulk piling for 30 days the same kind of stock had a degrade of only 28.5 per cent. The degrade charged to damaged knots was 15.4 and 14.9 per cent, respectively, while that charged to splits was 37.4 and 12.8 per cent, respectively. The moisture content of the stock at the kiln door averaged about 5 per cent and after storage 11 per cent.

Long periods of storage after drying, such as 6 to 12 months, are particularly beneficial, providing the stock does not pick up too much moisture, and even short periods of 10 to 20 days cause a marked improvement in flooring strips and narrow finish. Fifteen days in the rough shed raised the proportion on grade of 1 by 4 inch B and Better flooring strips from 88.5 to 92.7 per cent. Six months raised 1 by 8 inch B and Better from 87.5 to 94.6 per cent.

Storage in the rough shed for a minimum period of three weeks will prove economically worth while for the product of the ordinary type of natural-circulation progressive kiln, in which it is impracticable to follow a drying schedule that requires maintaining a humidity of at least 40 per cent for No. 1 Common and Better and 50 per cent for No. 2 Common stock. On the other hand, with kilns where these humidity conditions can be maintained there will not be enough saving in degrade to pay the handling costs of such storage. Where it is possible to steam the stock in the kiln immediately before removal, storage is not justified as a means of reducing degrade. Each handling of stock causes a certain amount of degrade, and the cost of handling and the attendant overhead suggest that such stock should be run direct from kiln to planer whenever possible. The sizes and grades in common demand can be run direct, and the storage shed can then be used to accumulate the items not moving rapidly, to permit the separation of grades, and to hold stock in the rough until it is needed to fill orders.

MACHINING KILN-DRIED STOCK

From a large number of moisture determinations on southern yellow pine that was leaving the planer, made in various studies of degrade, it appears that the range of moisture content through which the best planer work is obtained is from above 5 per cent to below 18 per cent. As the moisture content drops below 5 per cent, planer splitting, torn grain, and chipping increase, and above 20 per cent the surface is rough and fuzzy. There would be less damage to knots if the moisture content of the stock containing them were not below 7 per cent for knots up to 1 inch in diameter, and were 10 to 12 per cent and even higher for large knots. Most No. 1 Common and Better southern yellow pine, however, is used for interior work or in similar service in which the ultimate moisture content will ordinarily range between 6 and 9 per cent, and knotty stock admitted to these grades will have to run the risk of damage when it must be dried below 8 per cent. The uses to which No. 2 Common southern yellow pine is put are less exacting in regard to final moisture content and hence, whenever practicable, this stock should not be dried below 10 per cent. For low-grade lumber that contains an abundance of large knots the retention of a moisture content of at least 10 per cent is particularly important; to assure lowest degrade from knots, Schedule 108 should be modified so that the humidity will at no time go below 60 per cent. This can be accomplished by changing the conditions after 35 hours in the kiln from 190° F. dry bulb and 170° wet bulb to 200° dry bulb and 177° wet bulb.

PLANER DEFECTS

In common practice substantially all degrade occurring at the planer has been charged against the seasoning method and the planer itself has been considered responsible only for the most obvious planer defects. Actually, however, the planer is responsible for an important although usually undetermined proportion of the so-called kiln degrade. For instance, in an investigation of the matter, inconsistencies between different tests on stock of the same grade and from the same kiln charge, run at different times, appeared plainly. Because of the test conditions the only inference that could be drawn from this observation was that the planer set-up was not always uniform and that some factor connected with the planer set-up was responsible for the inconsistency.

It is to be expected that degrade will be least in narrow stock and greatest in wide stock and in degrade tests this expectation holds for stock 6 inches and wider but not for flooring strips. In fact, flooring often has a higher degrade than the widest stock run, although the degrade in 4-inch stock when surfaced four sides is very low. The factor causing most of the degrade in flooring strips is broken tongues and grooves, primarily a machine defect and not a kiln defect, and if this factor were excluded the degrade in the narrow stock would generally be lower than that in wide stock.

A tally was made of some B and Better flooring that had been very carefully dried and conditioned in the kiln. Tests before planing showed that the stock was free from casehardening and had quite a uniform moisture content, which averaged 8 per cent. The object of this test was to determine separately for each item the percentage of tongues and grooves that were broken sufficiently to cause a drop in grade. Table 13 presents the results of the test.

TABLE 13.—*Comparison of degrade in edge-grain and in flat-grain southern yellow pine flooring*

Type of flooring	On grade	Broken tongues	Broken grooves	All other defects
	Per cent	*Per cent*	*Per cent*	*Per cent*
Edge grain	76.10	3.25	16.30	4.35
Flat grain	96.43	.60	1.78	1.19

Edge grain is more liable to planer damage than flat grain on account of splitting along the growth rings in the thin, projecting tongues and groove sides, since the rings are at right angles to the projections in edge grain and parallel in flat grain. Most of the broken grooves develop in the flange that is uppermost as the piece goes through the planer.

The tests involving planer defects indicate that the machining operation is in need of improvement, that the planer set-up is not always uniform, and that outfeed rolls and the pressure bar are not always best suited to the item being manufactured.

PROTECTING THE FINISHED PRODUCT

After stock has left the kilns further changes in moisture content depend upon the conditions to which it is exposed, as has been explained under "Storage after kiln drying and before machining." After machining, many stock items are stored in bundles, sometimes on end in the finish shed, a form of storage that permits fairly rapid equalization where the stock is below the equilibrium moisture content at the time of machining.

The equilibrium moisture content for stock fully exposed to the atmosphere, under sheds, will vary more or less with the season and somewhat with the locality. During dry spring and summer weather the moisture content of stock after several weeks of such storage may not exceed 7 to 9 per cent. During average winter weather it may go to 11 or 12 per cent, and during protracted damp weather in any season it may run as high as 14 per cent. Some localities have more dry or more damp weather than others. Some mills have sheds that are very open and consequently react to outside weather conditions more quickly than those that are more protected.

Where it is desired that the moisture content of the stock in storage be kept below 9 per cent at all seasons, the sheds should be made tight and some method of heating should be provided. To hold stock below 9 per cent moisture content at an average temperature of 70° F. requires a relative humidity of about 47 per cent (fig. 3). If the humidity is above 50 per cent at this temperature, the heating coils can be turned on and the humidity thus lowered. Heat may be required even in the summer if the weather is damp, but in the United States it will certainly be needed continuously during cold weather.

The operators who handle stock carefully to prevent moisture changes will need to consider the storage conditions at wholesale and at retail distributing points fully as important as their own. Since stock may be held at each of these points for any length of time up to several months, the period of storage after stock leaves the mill may easily be far greater than that of the storage at the mill. Such operators, therefore, should decline to accept responsibility for the ultimate moisture content of properly dried stock when later storage conditions are unsatisfactory.

MOISTURE CONTENT OF LUMBER ON SHIPMENT AND ON RECEIPT

In order to obtain comprehensive information on the moisture content of softwood lumber at the time of shipment from representative first-class mills, the Forest Products Laboratory has carried out an extensive survey. It was conducted during the winter of 1926–27 in five softwood regions, namely: The southern pine region, the Inland Empire,[18] the Pacific Northwest,[19] the redwood region, and the California pine region, during the summer of 1927 in the southern pine region, and again during the summer of 1928 in the Inland Empire, the Pacific Northwest, and California. The tests were made on lumber just as it was being shipped and on as wide a variety of grades and products at each mill as the shipments permitted. In some cases the stock had been machined as it left the dry kiln, whereas in other cases it had been taken from the rough shed to the machine. When the stock had been stored, the time in the rough shed became a factor of some importance because of its effect on the moisture content. As explained on page 59, stock so stored over long periods tends to come to a moisture content in equilibrium with the atmospheric humidity; this moisture content has been found to vary from 10 to 13 per cent for stock that had been stored for several months in various rough sheds in the southern pine region. The average moisture content of 4/4-inch shortleaf stock, taken from the storage sheds, was found to be 10.5 per cent in summer and 11.6 per cent in winter. The average moisture content of longleaf pine was approximately 8 per cent in both the summer and the winter survey, but the storage period averaged 50 per cent longer in the summer than in the winter. Direct from the kiln, the average moisture content of the shortleaf in summer was 9.6 per cent and in winter 9.8 per cent, and of the longleaf was 8.1 per cent in summer and 9.1 per cent in winter. The average moisture content of different lots—that is, of various items of a shipment—varies somewhat both above and below the figures given, particularly for the stock tested as it left the kilns. The tests on car shipments proved that moisture pick-up in dry stock during transit is negligible even in very wet weather, provided that the freight cars are reasonably tight. Exposure to rain during loading or unloading, however, may be quite important.

DRY-KILN CONSTRUCTION AND MAINTENANCE

A discussion of dry-kiln construction in general is not within the province of this bulletin but, since dry kilns are subject to certain conditions not common to other types of structures, it seems worth

[18] Northwestern Montana, Idaho north of the Salmon River, Washington east of the Cascade Mountains, and the northeastern tip of Oregon.
[19] The wooded country in Washington and Oregon west of the crest of the Cascade Mountains.

while to comment on these conditions. The dry-kiln structure, regardless of the materials used, deteriorates more rapidly than ordinary buildings. Probably the principal cause, where brick, tile, or concrete is used, is the wide temperature changes and the resultant expansion and contraction of the walls and roof. If the kilns could be kept at a temperature nearly constant, passing only through the relatively small range occurring in the drying schedule, the effect of thermal expansion would be negligible. At times, however, it is necessary to shut down the kilns, and the walls contract as they cool, nearly to atmospheric temperature, and expand again when the heat is turned on. Cracks that develop as a result of this extreme condition continue to grow larger and larger. The long interior partitions of a battery and the outside walls parallel to them are usually cracked close to the doors, and monolithic concrete roofs, especially those on batteries of many units, tend to push the outside walls out of plumb, so that it is not uncommon in old batteries to see such walls braced to prevent them from falling outward.

While expansion and contraction can not be avoided, their bad results may be minimized. In order that this may be done, first, the shutting down of the kilns should be avoided as far as possible and, when a shutdown is unavoidable, the doors should be kept closed to retain the heat as long as possible. If the shutdown is for a short time, doing this will prevent contraction, and if for a long time will equalize it. Then when pointing up cracks in masonry, instead of mortar an elastic putty should be used, one that can expand and contract with the changes in the size of the crack. Such a putty, which is used around windows in brick walls, can be purchased from dealers or can be made up by mixing asbestos flour in asphaltic paint. In new batteries, a dovetail expansion joint should be provided in brick, tile, or concrete end walls and interior partitions, 4 to 6 feet back from the doors. This joint should be about one-half to three-quarters inch wide on the face of the wall and should be pointed up with elastic putty. Concrete roofs should be provided with a 1-inch expansion joint over every other bearing wall.

Heat passes through concrete more readily than through other usual building materials; brick, tile, and wood follow concrete in heat conductivity, in the order given. Vapor also passes through concrete to such a degree that operators find it more difficult to maintain high humidities in concrete kilns than in brick or tile kilns. Good, hard, burned brick, laid in tempered cement mortar, makes about as suitable a material for walls as can be obtained. Tile sometimes disintegrates under kiln conditions, and the expansion cracks in tile walls seem to be larger than those in brick walls, probably because of the larger individual unit in tile construction. There are many tile kilns giving satisfaction in service, however, and the tile and concrete-joist construction seems to make a very serviceable type of roof. Only the best quality, thoroughly burned tile or brick should be used in kiln construction; soft, underburned tile and brick disintegrate rapidly when subjected to the various combinations of heat and moisture in the kiln.

Where insurance rates and other limitations permit, a well-built wooden kiln is reasonably satisfactory. The high temperatures used in southern pine kilns cause a slow breaking down of the wood sub-

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Artificial smoke showing the leakage of air into a natural-circulation kiln at the bottom of a door. Inleakage occurs through any openings in the lower half of such kilns, and outleakage in the upper half

stance through a process of distillation, which shortens the life of the kiln. This process is much more rapid at temperatures above 220° than below 200°, and if wood is used the lower maximum temperatures are suggested as a means of prolonging the life of the kiln.

Doors too frequently are the source of enormous heat and vapor loss, and the cause of unequal drying near the ends of the kiln. Practically no design of door has worked out satisfactorily in all respects. The requirements of a good door are that it be tight fitting to prevent leakage (pl. 9), light in weight for ease in handling, and well insulated to conserve heat and thus prevent unbalancing of the kiln circulation.[20]

A very good door is made of wood and 3-ply roll roofing, using three thicknesses of 1-inch wood for the stiles and the rails, two thicknesses of the felt separated 1 inch for the panels, and one-half by 3-inch strips protecting the felt. Sometimes, in southern pine kilns, the inside of such a door is covered also with sheet metal. Asbestos composition board is sometimes used in place of the felt for the panels, in which event the wood protecting strips are dispensed with. Doors of the general type described are comparatively cheap, are easy to repair, and may be built by the plant carpenters.

Doors are sometimes made of light angle iron covered with corrugated iron, which in turn is covered with roofing felt. Some additional insulation, such as 1-inch sheet cork, should be used on such doors, since otherwise the heat loss through them is too great.

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[20] Clouds of vapor escaping around the door jambs indicate loose-fitting doors. A door that is uncomfortably warm to the hand is poorly insulated; this test should be made when the kiln is operating at the highest temperature of the drying schedule.

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SELECTIVE LOGGING IN THE NORTHERN HARDWOODS OF THE LAKE STATES

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United States Department of Agriculture, Washington, D. C.

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UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

SELECTIVE LOGGING IN THE NORTHERN HARDWOODS OF THE LAKE STATES

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CONTENTS

FOREWORD

Selective logging is fundamental to industrial forestry in the northern hardwood forests of the Lake States and accordingly an intensive study of this subject merits the attention of all timberland owners not only in that region, but in other hardwood regions as well.

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[1] The authors acknowledge their great indebtedness to their coworkers, A. M. Koroleff, R. M. Brown, and S. R. Gevorkiantz, of the Lake States Forest Experiment Station, and to Ray Miller, W. E. Griffee, and A. C. Wollin, of the Forest Products Laboratory, for their valuable assistance in planning the work and in collecting, computing, and analyzing the field data which form the basis for this report. Thanks are also due to J. D. Mylrea. of the Thunder Lake Lumber Co., Rhinelander, Wis.; to J. M. Bush and F. W. Hyde, of the Cleveland-Cliffs Iron Co., Marquette, Mich.; to E. A. Hamar, of the Worcester Lumber Co., Chassell, Mich.; to B. D. Stone, of the Bissell Lumber Co., Tripoli, Wis.: and to Henry Schmitz, of the College of Forestry, University of Minnesota, for their generous cooperation and assistance in the conduct of this investigation. O. T. Swan, secretary of the Northern Hemlock and Hardwood Manufacturers' Association, gave valuable suggestions in planning the investigation and was instrumental in disseminating the preliminary results among millmen and landowners in the Lake States.

[2] Maintained by U. S. Department of Agriculture at St. Paul, Minn., in cooperation with the University of Minnesota.

[3] Maintained by U. S. Department of Agriculture at Madison, Wis., in cooperation with the University of Wisconsin.

Selective logging as contrasted with the usual clear cutting of northern hardwoods, or to the "creaming" or "high grading" of the choicest timber, is a distinctly constructive, perpetuating measure which leaves the forest in a healthy, thrifty, and vigorous growing condition. While selection by species and also by sizes is not new to loggers of northern hardwoods, selective logging as referred to in this bulletin involves something of a new point of view and procedure. Thus, the term as used by the authors denotes a partial cutting practice which, by a judicious selection of the trees to be removed, meets both the silvicultural and present economic requirements, in such a way as to perpetuate and improve the forest and at the same time maintain or increase the profits to the owner.

Selective logging is a cutting method particularly suited to saw-timber operations in mixed uneven-aged forests, such as the northern hardwoods. Moreover it conforms closely with the general economic requirements of the Lake States in that it offers a method of keeping forested areas in crop production and prevents further increase in the deforested area.

Viewed broadly, the facts brought out in this publication should serve in establishing a forest plan which not only results in successive crops of valuable saw timber but establishes a system of stable land ownership and land use that contributes substantially to the economic welfare of the region.

R. Y. Stuart, *Forester.*

THE PROBLEM

The Lakes States lumber industry was developed on the assumptions that the greater part of the cut-over land would be cleared for agriculture and that the rest, apparently unfit for farming or for the profitable growing of a new crop of trees, would be worthless. Lumbermen therefore clear cut the forest, taking all trees about 9 inches or larger in diameter, of which it now seems probable the smaller sizes were handled at a loss. Selective logging, which may be defined as a partial cutting practice involving a judicious selection of the trees to be removed so as to perpetuate and improve the forest and at the same time maintain or increase the profit to the owner, was not consciously practiced or seriously considered. But neither of the original assumptions turned out to be wholly correct. Only a very small percentage of the cut-over land has been actually cleared and farmed, and practically all of the cut-over land can be made to grow a new crop of trees.

The lumbermen in the Lake States can no longer move on to virgin hardwoods after having cut out their holdings. They have a choice of two lines of action—to sell their equipment in a short time and go out of business, or to perpetuate their timber supply by practicing forestry on their holdings. Quite naturally many lumbermen want to stay in the business and these lumbermen realize the need of information on the following major problems: (1) How to restock the cut-over areas, and (2) how to manage the remaining stands in order to make them go as far as possible in providing a continuous supply of timber. This bulletin deals with the second problem.

PURPOSE OF INVESTIGATION

The specific aim of this bulletin is to present the comparative results of selective and clear cutting on typical lumber operations in the northern hardwood type of timber in the Lake States. The investigation described here involved ascertaining (1) the cost of logging and milling trees of different sizes and species; (2) the quantity, grade, and value of lumber produced from them; and (3) the net returns when different proportions of the total stand were removed for lumber under selective cutting. The Lake States Forest Experiment Station and the Forest Products Laboratory have long recognized that the forest owner in the Lake States who wishes to provide a permanent supply of timber by a more conservative handling of his remaining stands requires information of this character.

WHERE THE INVESTIGATION WAS MADE

The investigation was made at four lumber operations, two of which were located in northern Wisconsin and two in the Upper Peninsula of Michigan. These operations were generally representative of the region as regards daily output, methods of logging and milling, and character of the stand.

The field work was carried on cooperatively by the Lake States Forest Experiment Station, St. Paul, Minn.; the Forest Products Laboratory, Madison, Wis.; and individual members of the Northern Hemlock and Hardwood Manufacturers' Association, during the summers of 1925 and 1926.

HOW THE WORK WAS DONE

The investigation was carried on by a crew consisting of from four to eight men who went into the woods and mills and determined the output per unit of time and the cost per thousand board feet for each step of lumber manufacture from logs and trees of different sizes. In addition the lumber from each log was graded and tallied separately, and a cruise of the trees on several sample plots was made before logging began so that it was possible to determine how the logging and milling costs and lumber values would be affected if certain sizes of trees were not cut.

The ideal way to conduct an investigation of this kind would be to study the same logs in the woods as are studied in the mill so that logging and milling information for trees could be built up by simply adding together the data for the individual logs which made up each tree. Such a plan, however, was impracticable at the operations where the investigation was made. Consequently, the logs studied in the woods were similar but not identical with those at the mill. For this reason the information on logs had to be converted into terms of trees, and the trees into terms of the stand by an indirect method which is described later. The mills during the investigation, however, were getting their logs from the same areas on which the woods studies were made. That the logs were comparable in size is shown by the fact that the average diameter of the logs studied at the mill was 12.2 inches and in the woods 12.3 inches.

In developing the technic for this study the work of Ashe (*1, 4, 5, 6, 7, 8*)[4], Bradner[5] (*10, 11, 12, 13*), Bruce (*14, 15*), Bryant (*16, 17*), Chapman (*18, 19*), White (*22, 23*), and other investigators (*9* and *21*)[6 7] has been referred to freely.

DETAILED DESCRIPTION OF METHODS FOLLOWED

A more detailed explanation of the manner in which the investigation was made is given below.

The investigation was confined to sugar maple (*Acer saccharum*), yellow birch (*Betula lutea*), and eastern hemlock (*Tsuga canadensis*).

Sample plots of 5 acres each were laid out on three of the operations studied. All timber on these plots 4 inches and larger in diameter was tallied before and after logging. The total volume of the stand was then computed from volume tables. The results were segregated by diameter classes and species, so that the volume removed and left and its distribution could be determined by diameter classes and species. This information was also used in computing weighted average costs and lumber values, and in determining the production costs and lumber values where only a certain proportion of the stand is cut under selective logging.

The scale of each log was obtained by using the Scribner Decimal C log rule, which is the official rule of the Forest Service and the legal rule in Wisconsin, although not in Michigan.

The tree diameters were measured to the nearest tenth of an inch and the log lengths to nearest tenth of a foot; log diameters were determined to the nearest inch.

Members of the crew accompanied the loggers in the woods and by means of stop watches determined the time required for felling and bucking each log and tree just as it was handled in the regular logging operation. In addition they calculated the board-foot contents of each log with a scale rule and obtained measurements for each tree. They also timed the skidders, scaled the log or logs in each skid load, and measured the distance covered by the teams on each trip. Figures on loading were obtained by timing and scaling the logs as they were loaded on the cars. A similar method was used for unloading. Where stop-watch methods could be followed, production costs were computed as illustrated in the following example: The stop-watch records showed that 176 minutes were required to buck 1,000 board feet of 13-inch logs. Based on the wages paid at the time of the study, a sawyer received \$0.0113 a minute. Therefore, the cost of sawing for logs of this size was $\$0.0113 \times 176$ or \$1.99 a thousand board feet log scale.

In railroad operation and maintenance the direct time method of calculating costs could not be used, so that the cost for this item for different diameter classes of logs was based on the cost of a car trip and the comparative capacity of a standard car loaded with logs of different sizes.

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[4] Italic numbers in parenthesis refer to Literature Cited on page 45.

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The work at the mill was carried on by a crew of six men, stationed in such a way that complete records were obtained for each log from the time it came on the log deck to the time it passed out of the mill on the green chain in the form of lumber. One man scaled and numbered the logs as they entered the mill and recorded their diameters and lengths. One man noted the time required at the head saw to saw logs of different diameters. One or two men, according to the layout of the mill, placed the log number on each board or cant as it came from the head saw so that the lumber from each log could be identified on the green chain. Another man numbered similarly the lumber as it was sawed from cants, slabs, and flitches at the resaw. Finally a lumber inspector and a tallyman graded and tallied the lumber on the green chain for each log. Sugar maple and yellow birch were graded in accordance with the official rules of the National Hardwood Lumber Association, and hemlock was graded according to the Northern Hemlock and Hardwood Manufacturers' Association rules.

The comparative cost of sawing lumber from logs of different sizes was computed from the actual time required by the mill to produce a thousand board feet of lumber from logs of different diameters and the cost of running the mill for a corresponding period.

Production costs, such as selling lumber, insurance, and taxes, were considered constant for each thousand board feet regardless of the size of log, and therefore could be added without change to the direct-production cost for each diameter class.

Items of cost, such as railroad, road, and camp construction, were considered fixed charges per acre, and for this reason their cost per thousand board feet varied directly with the amount of timber removed per acre. If all the merchantable timber is removed, for example, the average cost per thousand board feet may be added to other log-run costs without change; if, however, only part of the timber is cut the cost of permanent improvements, such as railroad construction, must be proportionately higher.

The lumber prices used in this bulletin were the market quotations prevailing in the Lake States in 1925 and 1926 at the time the investigation was made. The average value of the lumber was computed on the basis of market prices and the grades obtained from the logs of different sizes.

In the woods the direct costs were changed from a log to a tree basis by determining the diameter of the average log in each diameter class of trees. This was done by dividing the merchantable height of each tree by 16 (the log length); then, by dividing the total merchantable volume of the tree by this quotient to obtain the volume of the average log. From this volume figure the corresponding diameter was read directly from the Scribner log rule. The cost of logging trees per thousand board feet gross log scale was then obtained by reading directly from the data on logs the cost of handling a log corresponding to the size of the average log in each tree class. For example, the log of average volume in a tree 20 inches in diameter is about 13.8 inches in diameter; therefore, the cost on the average, of sawing a thousand board feet was considered to be the same for trees 20 inches in diameter breast high as for logs 13.8 inches in diameter inside the bark.

In milling, instead of using the average log method just described, the diameter and volume of each of the logs that made up a tree of a given diameter class were determined from tree form curves made during the investigation. Average figures for grades, volume, and the cost of sawing for each size of log that made up a tree of a given diameter and height were read directly from the log tables and added together to give results for the entire tree. This same procedure was followed for each species and diameter class, thus giving figures for the stand as a whole.

The direct logging and milling costs and lumber values for individual trees were translated into the terms of the forest as a whole by applying figures from the sample plot data, showing the proportion of each species in the stand and the percentage of the total volume in each diameter class.

The log-run production costs and lumber values for the stand, when trees below certain diameters are omitted from the cut, were determined by applying the volume distribution figures for the stand, obtained from the tally made on the sample plots to the production costs and lumber values for trees of different diameters. An example of this computation is given on page 30.

The investigation covered time records and measurements of 900 trees for sawing timber; 1,200 trips for skidding; 2,400 logs for loading, unloading, and railroad operation and maintenance; 3,647 logs for milling; and the tally of all trees 4 inches and larger on sample plots of 5 acres each at three operations.

THE DEGREE OF GUIDANCE THAT THE RESULTS AFFORD THE LUMBERMEN

The figures on production costs, lumber values, profits, and cutting limits, which are given later in a series of tables, apply directly only to the conditions encountered and described, and are not applicable in their entirety to individual hardwood-hemlock lumber operations. This is to be expected because the production costs and the value of lumber vary with the amount of timber cut per acre, the proportion of trees of different diameters in the stand, the prevalence of eastern hemlock or any other species, and the prevailing lumber prices and wage scales. The trends established by these figures, however, may be expected to hold true generally throughout the Lake States region.

The results apply only where the logs are cut into lumber. The investigation was confined purposely to lumber because it is the main product of most of the mills of the Lake States. Furthermore, the lumbermen know how to manufacture and market it expertly, and for this reason they may be expected to develop future plans with the production of lumber in view. Where methods of manufacture and markets are such that small trees and tops of large trees are not cut into lumber but utilized for fuel, pulp wood, mine props, dimension stock, and similar purposes the financial aspects would change. This bulletin makes no attempt to forecast the results under such conditions.

The degree of guidance offered by this bulletin to the individual operator will depend on how closely the operations studied parallel his own. If his costs and species of wood correspond closely, he can use the results as a guide without further computation. If they do not, it will be necessary for him to take the basic figures given here and work out the results for his own operation.

In any event the guiding principles as to the comparative production costs and lumber values for trees of different sizes and species should apply generally within the Lake States region. Nevertheless, it is recommended that each lumberman work out specific figures for his own operation. Suggestions for computing diameter cutting limits are therefore given in the "Supplementary information" at the end of this bulletin.

PRODUCTION COSTS

LOG-RUN PRODUCTION COSTS

The following log-run costs of lumber production were used in the investigation as a basis for computations. They are an average of the costs supplied by the cooperating companies.

TABLE 1.—*Log-run production costs per thousand board feet*

[Based on companies' figures]

Woods operation	Cost, gross log scale, all species	Mill operation	Cost, lumber tally, for—	
			Hardwoods	Hemlock
Sawing (felling, bucking, and limbing)	$2.08	Milling	$5.02	$3.21
Skidding	2.56	Depreciation	.44	.32
Loading	.69	General expense	2.11	1.79
Railroad transportation	2.90	Sorting and piling	1.56	1.12
Unloading	.15	Yard maintenance	.36	.16
Railroad construction	2.44	Taxes on yard stock	.51	.28
Logging road construction	.41	Insurance on stock	.32	.13
Camp construction	.44	Shipping lumber	1.65	1.21
Woods supervision	.54	Selling lumber	1.04	.72
Woods general expense	.64			
Taxes on logs	.10	Total	13.01	8.94
Insurance on logs	.10			
Total	13.05			
Total woods cost, lumber tally (with 18.1 per cent overrun as determined by this investigation)	11.05			

With the above figures as a basis and by means of time studies the production costs for each diameter class and for different cutting limits were determined and are given later.

CLASSIFICATION OF PRODUCTION COSTS

In determining the production cost per thousand board feet for trees and logs of different sizes and when cutting to different diameter limits it was necessary to recognize that some items of cost vary with the size of the log or tree, others with the amount cut per acre, and still others remain constant.

The classification of costs used in this analysis is as follows:

Costs that vary per thousand board feet with the size of log or tree: Woods—Sawing, skidding, loading, railroad operation and maintenance (hauling), and unloading. Mill—Sawing logs into lumber, depreciation of mill and equipment, and general expense at mill.

Costs that vary per thousand board feet with the amount cut per acre: Woods—Railroad construction, logging roads, camp construction, woods supervision, and woods general expense.

Costs that are constant per thousand board feet: Woods—Taxes, and insurance on logs. Mill—Sorting and piling, yard maintenance, insurance on stock, taxes on yard stock, and shipping and selling lumber.

LUMBER PRICES USED

The lumber prices listed in Table 2 and used in this report were the current prices f. o. b. mills where the investigations were made and are representative of 1925 and 1926 quotations.

TABLE 2.—*Current lumber prices f. o. b. mills, 1926 and 1927*

Grade	Sugar maple	Yellow birch	Grade	Eastern hemlock
FAS	$80	$110	Merchantable	$27.00
Selects	70	85	No. 3 Common	18.00
No. 1 Common	57	55	No. 4 Common	11.50
No. 2 Common	33	33		
No. 3 Common	17	19		

PRESENTATION OF RESULTS

Most of the cost figures given later in the report for logs and trees of different diameters are based on ratios established by time observations. To clarify and shorten the main discussion the results are discussed in terms of dollars and cents alone, instead of using a combination of costs, output, and time figures. The cost figures for different diameter classes bear the same relation to each other as the time figures and may be used by an operator in working out cutting limits for his own operation to a much better advantage than the time ratios. Some additional information, not necessary in developing the principal points of the investigation, is given under "Supplementary information."

THE HARDWOOD-HEMLOCK FOREST OF THE LAKE STATES

LOCATION, AREA, AND STAND

The hardwood-hemlock forest considered in this bulletin occupies the fresh, well-drained, fertile soils of the northern pine region, located for the most part in northern Michigan and Wisconsin on the rolling glaciated land about the Great Lakes. It is roughly estimated that this forest still occupies 7,000,000 acres of land and supports a merchantable stand of hardwoods and hemlock totaling 56,000,000,000 feet, 11,000,000,000 feet of which is in Wisconsin and 29,000,000,000 feet in Michigan (*20*). Of the stands in Wisconsin and Michigan probably one-third is eastern hemlock and the rest hardwoods. Although there is a large quantity of hardwood timber in Minnesota, most of it is of a different quality and character than the stand in Michigan and Wisconsin.

COMPOSITION

This forest is made up of three main species: namely, sugar maple, yellow birch, and eastern hemlock. (Fig. 1.) Several other species, including basswood (*Tilia glabra*), beech (*Fagus grandifolia*), elm (*Ulmus americana*), and northern white pine (*Pinus strobus*) occur in small amounts in mixture with the above species, but taking the region as a whole these species are of considerable less importance than the sugar maple, yellow birch, and eastern hemlock, and are not considered in this bulletin. Originally, individual trees of northern white pine were found growing among the hardwoods, but most of them were cut prior to the present century. Many of the old stands have been logged lightly for hemlock, elm, or basswood, when the market was especially good for these species. The removal of the northern white pine and occasionally of other species gave predominance to sugar maple and yellow birch, but otherwise left the forest intact. The hardwood-hemlock forest may therefore still be classed as virgin forest supporting a stand varying from 5,000 to 15,000 board feet an acre.

The character of the forest in which this investigation was made can best be judged by the distribution of the volume of the different species in the stand by size classes.

TABLE 3.—*Number of trees of different sizes in the stand and their proportionate volume by diameter classes*

[Average of 15 acres]

Diameter breast high (inches)	Trees per acre	Proportion of stand by number	Proportion of stand by volume	
			Log scale	Board measure
	Number	*Per cent*	*Per cent* [1]	*Per cent* [1]
4	16	10.4	(2)	(2)
5	16	10.4	(2)	(2)
6	12	7.8	(2)	(2)
7	12	7.8	(2)	(2)
8	9	5.8	(2)	(2)
9	9	5.8	0.6	0.7
10	9	5.8	1.7	2.0
11	8	5.2	2.8	3.2
12	10	6.5	3.7	4.2
13	6	3.9	4.6	5.0
14	6	3.9	5.3	5.7
15	6	3.9	6.0	6.3
16	6	3.9	6.6	6.8
17	6	3.9	7.0	7.1
18	3	1.9	6.9	6.9
19	2	1.3	6.6	6.5
20	2	1.3	6.2	6.1
21	2	1.3	5.8	5.6
22	2	1.3	5.4	5.2
23	2	1.3	5.0	4.7
24	3	1.9	4.5	4.2
25 and up	7	4.5	21.3	19.8
Total	154	100±	100.0	100.0

[1] For the trees with diameters of 18 inches or larger, the decreasing volumes with increasing diameters is due to defect in the large overmature trees.
[2] Negligible.

FIGURE 1.—Typical hardwood-hemlock stand of timber in the Lake States

TABLE 4.—*Volume distribution in the stand of the predominant species by diameter classes*

Diameter breast high (inches)	Sugar maple		Yellow birch		Eastern hemlock	
	Gross scale basis	Lumber tally basis	Gross scale basis	Lumber tally basis	Gross scale basis	Lumber tally basis
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
9	68	67	16	15	16	18
10	74	73	14	13	12	11
11	77	77	13	12	10	11
12	79	78	13	12	8	10
13	80	80	13	12	7	8
14	80	80	14	13	6	7
15	81	81	14	13	5	6
16	80	80	15	14	5	6
17	79	80	16	15	5	5
18	78	79	17	16	5	5
19	77	77	18	17	5	6
20	76	77	18	17	6	6
21	75	76	19	18	6	6
22	73	74	20	19	7	7
23	71	72	21	20	8	8
24	70	71	21	20	9	9
25 and up	61	62	19	18	20	20
Log run	74	74	17	16	9	10

The figures in Table 3 show that the hardwood-hemlock forest is made up of trees of all sizes and that although the small trees are large in number their aggregate volume is small. Such a forest is well suited to selective logging.

Since sugar maple, yellow birch, and eastern hemlock are not of equal value, it was necessary to know the proportion of each in the stand before the log-run value of the timber could be computed. (Table 4.)

The log-run costs and lumber values for different cutting limits in this bulletin are based on the distribution of volume and species among the different diameter classes as shown in Tables 3 and 4.

ANNUAL CUT AND FUTURE OF THE INDUSTRY

According to census figures for 1925 the total cut of hardwoods and hemlock in Michigan and Wisconsin is about two billion feet annually. At this rate of production the supply of old timber will last until about 1945.

Figures compiled in 1924 by the Northern Hemlock and Hardwood Manufacturers' Association (*3*) show the future cut of the mills in the Lake States to be as follows: 17 per cent expected to be cut out in 6 years; 25 per cent in 10 years; 29 per cent in 15 years; 17 per cent in 20 years; and 12 per cent to last more than 27 years.

The figures, of course, are based on clear cutting, such as has been practiced in the past. If, on the other hand, some form of forestry is practiced, many of the mills can extend their life for several years, if not indefinitely. The hardwood-hemlock forest in which most of the mills are cutting is an uneven-aged stand containing trees of different sizes and according to the figures in this bulletin does not yield the highest returns when clear cut and manufactured into lumber, but it is ideally adapted to selective cutting. This is fortunate because by selective logging the forest offers to those who still have several years' future cut an opportunity to extend the life of their operations and to produce a high-grade product while they are doing it.

SIZE OF LOGS AND TREES AS A FACTOR IN LUMBER PRODUCTION

WOODS OPERATIONS

DIRECT COST OF LOGGING FOR LOGS OF DIFFERENT DIAMETERS

Lumbermen usually know fairly accurately their logging and milling costs as well as their profit or loss on the basis of log run, which comprises all log sizes. However, when a logger needs data on the cost of producing logs of a certain size he seldom has more than a vague guess to rely upon. The cost of logging, the value of the product, and the profit to the operator depend to a large extent on the size of the timber. It is, therefore, of great economic importance to the operator to know the relation of the size of timber to the cost and value of the lumber produced.

The results of the investigation regarding the effect of the size of the log upon the direct cost of logging are presented in Table 5. The figures in this table are the direct costs for each step of logging per thousand board feet, gross log scale, and exclude supervision, general expense, and investment in railroad, logging road, and camp construction; all of which do not vary with the size of the log or tree.

TABLE 5.—*Direct woods cost per thousand board feet, gross log scale of producing and handling logs of different sizes of all species studied*

[Includes only cost items that vary with the size of the log]

Top diameter inside bark (inches)	Sawing [1]	Skidding	Loading	Railroad operation and maintenance	Unloading	Total
	Dollars	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*
6	4.60	8.42	2.14	4.21	0.55	19.92
7	3.87	6.96	1.73	3.95	.43	16.94
8	3.35	5.79	1.42	3.68	.35	14.59
9	2.91	4.74	1.17	3.46	.29	12.57
10	2.60	3.87	.97	3.27	.24	10.95
11	2.34	3.15	.82	3.12	.19	9.62
12	2.16	2.59	.70	2.98	.16	8.59
13	1.99	2.18	.62	2.89	.14	7.82
14	1.88	1.92	.55	2.79	.12	7.26
15	1.77	1.71	.49	2.72	.10	6.79
16	1.69	1.56	.45	2.65	.10	6.45
17	1.62	1.45	.42	2.58	.09	6.16
18	1.57	1.40	.40	2.51	.08	5.96
19	1.52	1.37	.38	2.45	.07	5.79
20	1.47	1.36	.37	2.40	.07	5.67
21	1.43	1.36	.36	2.35	.06	5.56
22	1.40	1.37	.35	2.30	.06	5.48
23	1.37	1.40	.34	2.26	.05	5.42
24	1.35	1.43	.33	2.23	.05	5.39
Log run	2.08	2.56	.69	2.90	.15	8.38

[1] Sawing includes felling, limbing, and bucking.
From companies' figures.

The significant points to be kept in mind in connection with this table are (1) the increased cost of handling small logs as compared with large logs, and (2) the effect of the relative distribution of the cut among log sizes on the log-run cost of logging. With the distribution of log sizes found in these studies the log-run cost was $8.38 a thousand board feet, gross log scale. If a greater proportion of the logs had fallen in the smaller diameter classes the cost would have been higher; on the other hand, if the logs had run larger the logging cost would have been less. This point is well brought out in column 7 of Table 5 in which it is shown that the direct logging cost for 7-inch logs is $16.94 a thousand board feet, gross scale, as compared to $5.39 for 24-inch logs. The figures show, also, that the rate at which the cost of logging decreases with the increase of log diameter is much greater for small than for large logs.

RELATIVE COST OF THE DIFFERENT STEPS OF LOGGING

In every step of logging the total cost per thousand board feet is greater for small than for large logs. The rate at which the cost decreases with the increase in log size varies for the different steps in logging. This variation is illustrated by the 8-inch and 24-inch logs in Table 6, and is the largest for unloading logs and the smallest for railroad operation and maintenance.

TABLE 6.—*Approximate ratio between the direct cost of logging per thousand board feet, log scale, of 8-inch logs and of 24-inch logs*

Items	Ratio	Items	Ratio
Felling, limbing, bucking	2.5	Railroad operation and maintenance	1.6
Skidding	4.0	Unloading	7.0
Loading	4.3	All steps of logging	2.7

To make a close cost analysis of a logging operation requires a knowledge of the cost relation of each step in logging to the total cost when handling logs of different sizes. This relation between the cost of individual steps of logging and the total cost for logs of different sizes is brought out in Table 7. These figures show, for instance, that in handling 8-inch logs skidding is the largest item of expense, while for 24-inch logs railroad operation and maintenance is greatest. If an operator is handling extremely small logs, he should try to reduce the cost of skidding, while if he is handling large logs he should attempt to reduce transportation costs.

TABLE 7.—*Variation of the cost of the separate steps of logging with the size of the log*

Top diameter inside bark (inches)	Cost per thousand board feet, gross log scale, in percentage of total cost of logging for—					
	Sawing	Skidding	Loading	Railroad operation and maintenance	Unloading	Total
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
8	23.0	39.7	9.7	25.2	2.4	100
Log run	24.8	30.6	8.2	34.6	1.8	100
24	25.0	26.6	6.1	41.4	.9	100

THE DIFFERENT STEPS IN LOGGING

SAWING

The felling, limbing, and bucking of trees at the three logging operations studied were done by crews consisting of two men. Log sawyers were paid, as a general rule, on a linear-foot basis without regard to the diameter of the logs cut. Each crew of sawyers was assigned to a strip of timber which averaged about 300 feet in width and about one-fourth mile in length. The trees were usually felled in a haphazard way. Some of the sawyers tried to coordinate felling with skidding. They threw trees preferably in the direction of skidding, or in such a way that the tops of several trees came together in one pile. (Fig. 2, A.) Little care was taken in felling the trees to prevent breakage or injury to the remaining trees. Since slash disposal was not practiced, the tops and limbs were left in loose and irregular piles.

Log lengths varied from 8 feet to 20 feet. Most of the logs, however, were 12, 14, and 16 feet long, the latter predominating. The average length was close to 15 feet which included a trimming allowance of 3 inches.

The instructions to the sawyers as to the top diameter of the last log were not always definite nor strictly enforced. In small hardwood trees the top of the actually utilized bole was equal or even below the required minimum, whereas in large trees the diameter of the last log was much greater than that specified in the sawing instructions.

The smallest top diameter to which, according to company instructions, trees should be cut for lumber varied from 8 inches to 10 inches. Actually the trees were utilized to a top diameter of 6 inches to 14 inches, depending on their size. Since the sawyers were paid a flat rate per linear foot, they cut all the small trees that would pass inspection. For the same reason they cut up as much of the bole of small trees, which required little limbing, as the company would accept and cut as little of the tops of large trees, which required excessive limbing, as the company would allow. In several instances the companies accepted logs 6 inches in diameter, especially of birch, if they were straight, sound, and not knotty, although their instructions called for logs 8 inches in diameter and larger. Occasionally, a small log was rejected. The cut of each sawyer averaged 2,740 board feet, gross log scale, a day.

SKIDDING

Conditions under which skidding was done on the operations studied were typical of the hardwood-hemlock forests, namely, good bottom, fairly clear from obstructions, light underbrush, topography varying from flat to rolling and only occasionally rough. Skidding was done by horses working in single teams. Skidding tongs were used, and generally only one log was taken at a time. Small logs were sometimes skidded two or three at once with a skidding chain.

The railroad spurs were spaced on the average of about one-fourth mile apart and the logs were skidded directly to the railroad. The distance over which the logs were skidded was about 20 per

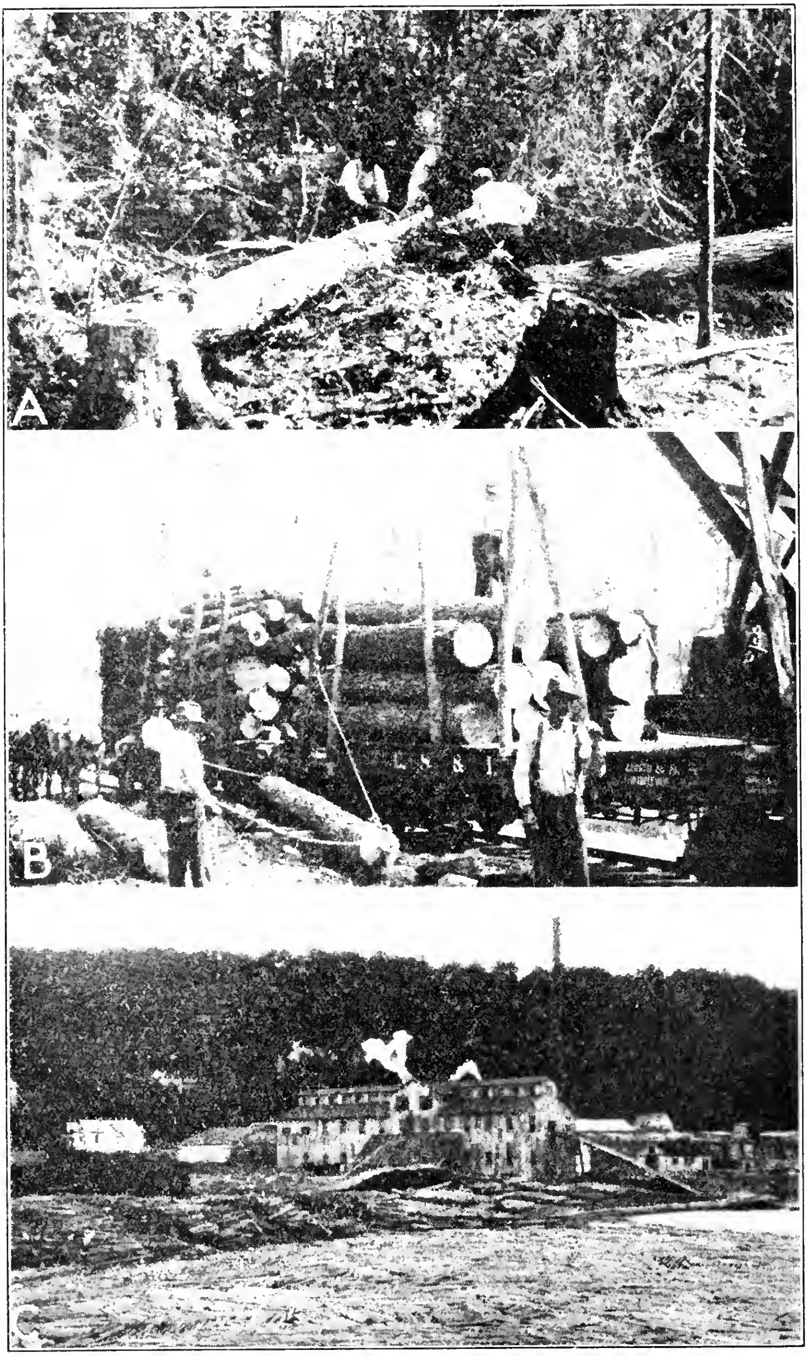

FIGURE 2.—Logging and milling operation in the Lake States: A, Cutting a sugar maple tree into log lengths; B, loading hardwood logs; C, a typical band sawmill

cent longer than the straight distance between the stump and the skidway. The average skidding distance was thus approximately 400 feet.

Skidways were made at some operations on the average of 250 feet apart and the logs piled in one or two tiers equivalent to a carload or more. In other cases no skidways were made, and logs from a given area were skidded direct to the spur tracks at some convenient point, where the cars were spotted and loaded.

LOADING

In all the operations covered by the study, logs were loaded on cars by steam loaders. (Fig. 2, B.) The average carload capacity ranged from 2,000 board feet to 6,000 board feet, gross scale. The loading crew consisted of four to six men. The average output per day varied from 31,000 to 44,000 board feet, gross scale. Large logs were loaded singly; medium and small logs were usually loaded in bundles containing two to five logs. Occasionally from six to seven logs were bundled and loaded at one time.

RAILROAD OPERATION AND MAINTENANCE

Logs were hauled from the woods to the mill at three of the operations over a standard-gage railroad and at the fourth over a narrow gage. With the exception of an 18-mile haul over a common carrier at one operation, the railroads were owned and operated by the companies covered in the study. The railroad haul varied with each operation, the maximum variation being from 18 to 36 miles. At three of the operations ordinary flat cars were used for hauling logs, and stakes made from small trees were used to hold the logs on the cars. One operator used cars equipped with iron car stakes and patent stake-releasing devices. None of the railroad grades were steep enough to require geared engines, so the ordinary type of locomotive was used.

UNLOADING

The last step of logging—that is, unloading logs from cars into the mill pond—required but little work and the cost was relatively small.

Load-holding devices on one side of the car were released which allowed a part of the logs to fall off the car onto the unloading incline where they rolled into the log pond. The rest of the load was then rolled off the car with a cant hook.

DIRECT COST OF LOGGING TREES OF DIFFERENT DIAMETERS

Direct logging costs per thousand board feet for trees of different diameters are shown in Table 8. Since these costs were computed from the costs for logs as explained under "How the work was done" they quite naturally follow similar trends; that is, small trees have a much higher logging cost per thousand board feet than large ones. For example, the total direct cost of logging per thousand board feet for trees 10 inches in diameter is 2.3 times greater than for trees 25 inches in diameter.

Table 8.—*Direct woods cost per thousand board feet, gross log scale, of logging trees of different sizes of all species studied*

[Includes only costs that vary with the size of the tree]

Diameter breast high (inches)	Sawing	Skidding	Loading	Railroad operation and maintenance	Unloading	Total
	Dollars	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*
8	4.06	7.36	1.64	3.80	0.50	17.36
9	3.68	6.61	1.56	3.72	.46	16.03
10	3.38	5.94	1.46	3.63	.42	14.83
11	3.12	5.30	1.34	3.54	.36	13.66
12	2.91	4.73	1.18	3.45	.32	12.59
13	2.73	4.22	1.06	3.36	.28	11.65
14	2.57	3.76	.95	3.26	.24	10.78
15	2.42	3.36	.80	3.18	.21	9.97
16	2.29	3.00	.79	3.10	.19	9.37
17	2.18	2.67	.72	3.02	.17	8.76
18	2.08	2.41	.67	2.95	.16	8.27
19	1.99	2.19	.62	2.88	.15	7.83
20	1.91	2.00	.58	2.83	.13	7.45
21	1.85	1.88	.55	2.78	.13	7.19
22	1.79	1.76	.52	2.73	.12	6.92
23	1.74	1.66	.49	2.69	.11	6.69
24	1.69	1.57	.47	2.65	.11	6.49
25	1.64	1.51	.46	2.61	.10	6.32
26	1.60	1.46	.44	2.57	.10	6.17
27	1.57	1.43	.44	2.53	.10	6.07
28	1.53	1.39	.43	2.50	.10	5.95
29	1.50	1.38	.43	2.48	.10	5.89
30	1.48	1.31	.43	2.47	.10	5.79
Log run	2.08	2.56	.69	2.90	.15	8.38

OTHER LOGGING COSTS

In addition to the direct costs of logging shown in Tables 7 and 8, there are charges for railroad, logging road, and camp construction, also woods supervision, woods general expense, and taxes and insurance on logs; all of which are here termed other costs. These costs are listed in detail on page 7, and average $4.67 a thousand board considered as constant per acre, and are not influenced by the size of the timber except as overrun varies with trees of different sizes. These costs, however, vary directly per thousand board feet with the amount cut per acre.

TOTAL LOGGING COST

The total logging cost can be readily obtained by adding the other costs of $4.67 to the direct costs of $8.38, which are given in Table 5, making a total log-run logging cost of $13.05 a thousand board feet, gross log scale.

The log-run logging cost for each size of log or tree may be obtained by adding together the other costs and the direct logging costs of each diameter class. Such a computation, of course, assumes that the other costs are the same for individual diameters as for log run.

OVERRUN AFFECTS THE COST OF LUMBER MANUFACTURE

Before the total cost of lumber manufacture can be computed in board measure it is necessary to convert the logging costs from a log scale to a lumber-tally basis. This is done by applying an overrun figure.

Gross overrun is the amount by which the lumber tally exceeds the gross log scale. It occurs because the efficiency of the mill doing the work and the proportion of four-quarter-inch and eight-quarter-inch stock that is sawed can not be anticipated by the Scribner rule. Furthermore, the rule itself does not give consistent results for all diameters.

Table 9 gives the gross overrun for logs and trees of different diameters for all the species investigated. Overrun varies among species, but this fact has been taken into account and need not be considered here. For those interested in this phase, tables of net (gross scale minus deduction for defect) and gross overrun by species are given under "Supplementary information."

TABLE 9.—*Variation in gross overrun for logs and trees of different diameters for all species studied*

Logs				Trees			
Top diameter inside bark (inches)	Gross overrun (all species together)	Top diameter inside bark (inches)	Gross overrun (all species together)	Diameter breast high (inches)	Gross overrun (all species together)	Diameter breast high (inches)	Gross overrun (all species together)
	Per cent		*Per cent*		*Per cent*		*Per cent*
7	49.4	15	13.1	9	42.0	18	18.2
8	39.2	16	11.4	10	38.5	19	16.6
9	33.1	17	9.6	11	35.3	20	15.3
10	27.7	18	7.9	12	32.4	21	13.8
11	23.0	19	6.2	13	29.7	22	12.6
12	19.5	20	4.8	14	27.1	23	11.2
13	16.7	Log run	18.1	15	24.5	24	10.1
14	14.8			16	22.2	25	9.5
				17	20.3	Log run	18.1

Table 9 shows that overrun is greater in small logs and small trees than in large ones. Small logs and small trees yield more lumber per thousand board feet, log scale, than large ones, and in this way compensate to a considerable extent the normally greater cost of logging them; but even after this credit they are more costly to handle than large logs or trees. The following example illustrates this point:

The direct logging cost for 8-inch logs (Table 5) is $14.59 a thousand board feet, gross scale, or 2.6 times greater for 20-inch logs which cost only $5.67. The gross overrun for 8-inch logs is 39.2 per cent (Table 9) and for 20-inch logs 4.8 per cent. Reducing the above direct logging costs to a lumber tally basis by dividing them by 1 plus the overrun, they become $10.48 and $5.41, respectively. In terms of lumber tally the logging cost per thousand board feet for 8-inch logs is therefore only 1.9 times greater for 20-inch logs, as compared to the ratio of 2.6 on a gross log-scale basis.

The logging costs reduced to a lumber-tally basis given later in this bulletin were computed as illustrated by the following example:

Total log-run logging cost per thousand board feet, gross log scale	$13.05
Gross overrun for the log run in per cent	18.1
Total log-run logging cost per thousand board feet, lumber tally ($13.05 ÷ 1.181)	11.05

MILLING OPERATIONS

MILLING PRACTICE

The four sawmills at which the milling study was made were typical of the region. (Fig. 2, C.) They were equipped with one or more 6-foot to 8-foot band head saws and one 4-foot to 6-foot band resaw of either the vertical or the horizontal type, each cutting approximately 1/8-inch kerf.

With the large logs the general practice at the mills studied was to turn them on the carriage and saw either into standard lumber or into cants or flitches in a manner caluculated to produce lumber of the highest grade. Since most small logs yield little or none of the higher grades of lumber they were usually not turned on the carriage but were sawed through and through into flitches or lumber without particular regard to resultant grades. Sometimes small logs and the hearts of large logs were cut into ties. In such cases the lumber in them was graded as No. 3 Common. The logs varied in size from 7 to 20 inches in diameter and averaged about 12 inches.

Hardwoods were cut from four-quarter inch to twelve-quarter inch in thickness according to the anticipated or current market demand. Rough green dimensions of hardwoods for four-quarter-inch material were on the average one-eighth of an inch in excess of standard thickness, and widths were random. Eastern hemlock was largely sawed into thicknesses greater than four-quarter inch for dimension purposes. Six thirty-seconds of an inch in excess of yard standard thicknesses and from one-quarter inch to one-half inch in excess of the yard standard width were normally allowed in manufacturing eastern hemlock to compensate for shrinkage, sawing variation, and surfacing.

All lumber companies graded and tallied their lumber on the green chain. Sorting was done on the basis of green-chain grades, which did not necessarily correspond to standard grades, but in some cases were a combination, for example, No. 1 Common and Selects were often put in the same grade.

Lumber was piled separately by thicknesses, grades, and species. It was either kiln dried or air seasoned.

TOTAL MILLING COST FOR LOGS AND TREES OF DIFFERENT DIAMETERS

Sawmills in the Lake States are ordinarily manned and equipped in accordance with the output of the head saw. There must be sufficient men and machines behind it to take care of the lumber. When output at the head saw is at the maximum, all the machines and men are extremely busy; when output drops, the crew and equipment work at lower speed, but their hourly cost remains the same and hence the cost per thousand board feet of lumber increases. Such a variation in output occurs when sawing logs of different sizes because the output is heavy when sawing large logs and light when sawing small logs. The cost of sawing was therefore based on the comparative time required to saw 1,000 board feet of lumber at the head saw from logs of different diameters.

These costs are, of course, strictly applicable only to mills in which a resaw is used as an adjunct to the head saw. Since, however, this type of installation is characteristic of the region, there will be but few mills in which those costs will not apply.

Tables 10 and 11 give the total mill cost of producing lumber from logs and trees of different diameters for all species investigated in the proportion that they occurred in the stand. Direct costs, depreciation, and general expense have been considered as varying with the size of the log, while yard expense, such as sorting and piling (see p. 8), remain constant per thousand board feet for each species. Excluding the charges that remain constant, the mill cost per thousand board feet of lumber from 8-inch logs is 1.9 times greater than that from 20-inch logs. (Table 10.) If the charges remaining constant are included the ratio drops to 1.5. The milling costs for trees (Table 11) follow a similar trend, the total cost per thousand board feet for trees 9 inches in diameter is 1.4 times greater than for trees of diameters 25 inches and up.

TABLE 10.—*Milling costs per thousand feet, board measure, for logs of different diameters of all species studied*

Top diameter inside bark (inches)	Costs that vary with the size of log		Costs that are considered constant per thousand board feet by species [3]	Total
	Direct costs of milling [1]	General expense and depreciation [2]		
	Dollars	*Dollars*	*Dollars*	*Dollars*
7	6.67	3.59	4.86	15.12
8	6.79	3.51	5.27	15.57
9	6.35	3.26	5.33	14.94
10	5.85	2.99	5.36	14.20
11	5.36	2.75	5.37	13.48
12	5.06	2.58	5.38	13.02
13	4.87	2.50	5.37	12.74
14	4.72	2.41	5.36	12.49
15	4.58	2.36	5.36	12.29
16	4.45	2.28	5.33	12.06
17	4.29	2.23	5.28	11.80
18	4.13	2.14	5.23	11.50
19	3.99	2.09	5.16	11.24
20	3.49	1.92	4.71	10.12
Log run	4.98	2.58	5.26	12.82

[1] Milling cost.
[2] Depreciation of mill, equipment, and general expense.
[3] Sorting and piling, yard maintenance, insurance on stock, taxes on yard stock, shipping lumber, selling lumber. The variation of these items between different diameter classes is due to different proportions of hemlock and hardwoods.

TABLE 11.—*Milling costs per thousand feet, board measure, for trees of different diameters of all species studied*

Diameter breast high (inches)	Direct costs	General expense and depreciation	Costs that are considered constant per thousand board feet, by species	Total
	Dollars	*Dollars*	*Dollars*	*Dollars*
9	6.77	3.57	5.11	15.45
10	6.55	3.41	5.19	15.15
11	6.36	3.30	5.24	14.90
12	6.13	3.18	5.26	14.57
13	5.92	3.06	5.29	14.27
14	5.68	2.93	5.31	13.92
15	5.45	2.80	5.33	13.58
16	5.28	2.70	5.33	13.31
17	5.11	2.63	5.35	13.09
18	4.98	2.54	5.35	12.87
19	4.83	2.50	5.33	12.66
20	4.75	2.44	5.33	12.52
21	4.66	2.39	5.33	12.38
22	4.55	2.35	5.31	12.21
23	4.45	2.30	5.29	12.04
24	4.38	2.25	5.28	11.91
25	4.15	2.18	5.08	11.41
Log run	4.98	2.58	5.26	12.82

TOTAL LUMBER-PRODUCTION COST

The total log-run cost of lumber production in terms of lumber tally per thousand feet, board measure (for all species investigated and for logs 7 inches and larger in diameter and for trees 9 inches and larger in diameter), is obtained by adding the logging and the milling costs.

	Per thousand feet, board measure
Total logging cost (p. 7)	$11.05
Total milling cost (Table 9)	12.82
Total production cost	23.87

The foregoing total production cost does not include stumpage, profit, or interest on invested capital. Total lumber production costs by diameter classes are given later.

LUMBER GRADES

The production costs involved in manufacturing lumber from logs and trees of different diameters, unless coupled with a consideration of the different grades of lumber obtained from them, do not give a complete understanding of all the advantages in handling large logs and trees as compared to small ones. Not only do the production costs decrease with the increase in size of the log or tree, but the amount of the high-grade lumber and consequently the value rises with the increase in size.

LUMBER GRADES ARE HIGHER IN LARGE LOGS AND TREES

Tables 12 to 17, inclusive, give the grades and value of lumber obtainable from logs and trees of different sizes for sugar maple, yellow birch, and eastern hemlock.

TABLE 12.—*Grades of lumber and average value by diameter classes for sugar maple logs*

Top diameter inside bark (inches)	Percentage of lumber in green condition of grade—					Value per thousand feet, board measure	
	FAS	Select	No. 1 Common	No. 2 Common	No. 3 Common	Green [1]	Dry [2]
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Dollars*	*Dollars*
7			4.3	14.9	80.8	21.10	20.04
8		0.1	7.6	15.9	76.4	22.64	21.51
9	0.2	1.3	10.7	16.6	71.2	24.75	23.51
10	1.1	2.5	13.5	16.8	66.1	27.11	25.75
11	2.5	3.5	16.1	17.0	60.9	29.59	28.11
12	4.1	4.6	18.5	16.8	56.0	32.11	30.50
13	5.9	5.6	20.8	16.6	51.1	34.66	32.93
14	7.6	6.6	23.0	15.9	46.9	37.03	35.18
15	9.2	7.5	25.3	15.3	42.7	39.34	37.37
16	10.7	8.5	27.6	14.2	39.0	41.56	39.48
17	12.3	9.4	29.6	13.1	35.6	43.67	41.49
18	13.9	10.1	31.4	12.2	32.4	45.62	43.34
19	15.3	10.9	32.7	11.4	29.7	47.32	44.95
20	16.7	11.6	33.5	10.7	27.5	48.78	46.34
Log run	7.0	6.1	22.6	15.0	49.3	36.08	34.28

[1] Dry values based on volume when green and on the following prices f. o. b. shipping point: FAS, $80; Select, $70; No. 1 Common, $57; No. 2 Common, $33; No. 3 Common, $17.
[2] Dry value was obtained by reducing the green value 5 per cent to cover the loss caused by degrade and shrinkage during drying.

TABLE 13.—*Grades of lumber and average value by diameter classes for sugar maple trees*

Diameter breast high (inches)	Percentage of lumber in green condition of grade—					Value per thousand feet, board measure	
	FAS	Select	No. 1 Common	No. 2 Common	No. 3 Common	Green [1]	Dry [2]
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Dollars*	*Dollars*
9		0.6	8.2	12.3	78.9	22.57	21.44
10		1.2	9.6	13.5	75.7	23.64	22.46
11	0.4	1.7	10.9	14.5	72.5	24.83	23.59
12	.9	2.1	12.3	15.3	69.4	26.05	24.75
13	1.4	2.8	13.7	15.8	66.3	27.37	26.00
14	2.3	3.2	15.1	16.0	63.4	28.74	27.30
15	3.2	3.6	16.4	16.2	60.6	30.08	28.58
16	4.1	4.2	17.7	16.1	57.9	31.46	29.89
17	5.0	4.7	18.8	16.1	55.4	32.74	31.10
18	5.8	5.2	20.3	15.9	52.8	34.07	32.37
19	6.6	5.6	21.8	15.8	50.2	35.37	33.60
20	7.5	6.0	23.1	15.7	47.7	36.66	34.83
21	8.3	6.6	24.3	15.5	45.3	37.93	36.03
22	9.1	7.1	25.5	15.3	43.0	39.11	37.18
23	10.0	7.6	26.6	15.0	40.8	40.37	38.35
24	10.9	8.1	27.6	14.6	38.8	41.54	39.46
25	11.8	8.6	28.7	14.1	36.8	42.73	40.59

[1] Dry values based on volume when green and on the following prices f. o. b. shipping point: FAS, $80; Select, $70; No. 1 Common, $57; No. 2 Common, $33; No. 3 Common, $17.
[2] Dry value was obtained by reducing the green value 5 per cent to cover the loss caused by degrade and shrinkage during drying.

TABLE 14.—*Grades of lumber and average value by diameter classes for yellow birch logs*

Top diameter inside bark (inches)	Percentage of lumber in green condition of grade—					Value per thousand feet, board measure	
	FAS	Select	No. 1 Common	No. 2 Common	No. 3 Common	Green [1]	Dry
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Dollars*	*Dollars*
7	-----	-----	5.8	20.3	73.9	23.93	22.73
8	0.7	1.0	8.7	20.0	69.6	26.23	24.92
9	1.6	2.1	11.6	19.6	65.1	28.76	27.32
10	2.7	3.2	14.2	19.2	60.7	31.37	29.80
11	3.9	4.2	16.7	18.8	56.4	33.96	32.26
12	5.6	5.4	19.0	18.4	51.6	37.08	35.23
13	7.5	6.4	20.7	18.0	47.4	40.02	38.02
14	9.8	7.5	22.2	17.6	42.9	43.32	41.15
15	12.2	8.6	23.4	17.2	38.6	46.61	44.28
16	14.6	9.6	24.7	16.8	34.3	49.87	47.38
17	17.2	10.6	26.1	16.4	29.7	53.34	50.67
18	20.0	11.7	27.5	16.0	24.8	57.06	54.21
19	23.3	12.8	28.8	15.6	19.5	61.20	58.14
20	27.3	14.0	30.1	15.2	13.4	66.05	62.75
Log run	12.1	7.6	22.2	16.7	41.4	45.36	43.09

[1] Dry values based on volume when green and on the following prices f. o. b. shipping point: FAS, $110; Select, $85; No. 1 Common, $55; No. 2 Common, $33; No. 3 Common, $19.
[2] Dry value was obtained by reducing the green value 5 per cent to cover the loss caused by degrade and shrinkage during drying.

TABLE 15.—*Grades of lumber and average value by diameter classes for yellow birch trees*

Diameter breast high (inches)	Percentage of lumber in green condition of grade—					Value per thousand feet, board measure	
	FAS	Select	No. 1 Common	No. 2 Common	No. 3 Common	Green [1]	Dry [2]
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Dollars*	*Dollars*
9	0.5	0.5	6.9	24.4	67.7	25.68	24.40
10	1.3	1.2	9.0	22.5	66.0	27.36	25.99
11	2.2	1.8	11.1	20.7	64.2	29.08	27.63
12	3.1	2.6	13.0	19.4	61.9	30.93	29.38
13	4.0	3.2	14.6	18.3	59.9	32.57	30.94
14	4.8	3.8	15.9	17.5	58.0	34.05	32.35
15	5.7	4.5	16.9	17.1	55.8	35.64	33.86
16	6.6	4.9	18.0	16.8	53.7	37.07	35.22
17	7.4	5.3	18.8	16.6	51.9	38.32	36.40
18	8.3	5.8	19.5	16.7	49.7	39.74	37.75
19	9.2	6.2	20.1	16.7	47.8	41.04	38.99
20	10.0	6.7	20.8	16.8	45.7	42.36	40.24
21	11.0	7.2	21.5	16.9	43.4	43.87	41.68
22	12.1	7.7	22.4	16.9	40.9	45.52	43.24
23	13.3	8.2	23.4	16.9	38.2	47.30	44.94
24	14.5	8.9	24.3	16.9	35.4	49.18	46.72
25	16.2	9.6	25.4	16.9	31.9	51.59	49.01

[1] Dry values based on volume when green and on the following prices f. o. b. shipping point: FAS, $110; Select, $85; No. 1 Common, $55; No. 2 Common, $33; No. 3 Common, $19.
[2] Dry value was obtained by reducing the green value 5 per cent to cover the loss caused by degrade and shrinkage during drying.

TABLE 16.—*Grades of lumber and average value by diameter classes for eastern hemlock logs*

Top diameter inside bark (inches)	Percentage of lumber in green condition of grade—			Value per thousand feet, board measure	
	Merchantable	No. 3 Common	No. 4 Common	Green [1]	Dry [2]
	Per cent	*Per cent*	*Per cent*	*Dollars*	*Dollars*
7	60. 8	35. 4	3. 8	23. 22	22. 52
8	60. 8	34. 7	4. 5	23. 18	22. 48
9	60. 8	34. 0	5. 2	23. 13	22. 44
10	61. 0	33. 3	5. 7	23. 12	22. 43
11	61. 3	32. 6	6. 1	23. 12	22. 43
12	61. 8	31. 9	6. 3	23. 15	22. 46
13	62. 3	31. 2	6. 5	23. 18	22. 48
14	62. 8	30. 5	6. 7	23. 22	22. 52
15	63. 3	29. 8	6. 9	23. 25	22. 55
16	63. 8	29. 1	7. 1	23. 28	22. 58
17	64. 3	28. 4	7. 3	23. 31	22. 61
18	64. 9	27. 7	7. 5	23. 34	22. 64
19	65. 3	27. 0	7. 7	23. 38	22. 68
20	65. 8	26. 3	7. 9	23. 41	22. 71
Log run	61. 7	31. 9	6. 4	23. 14	22. 45

[1] Dry value based on volume when green and on the following prices f. o. b. shipping point: Merchantable, $27; No. 3 Common, $18; No. 4 Common, $11.50.
[2] Dry value was obtained by reducing the green value 3 per cent to cover the loss caused by degrade and shrinkage during drying.

TABLE 17.—*Grades of lumber and average value by diameter classes for eastern hemlock trees*

Diameter breast high (inches)	Percentage of lumber in green condition of grade—			Value per thousand feet, board measure	
	Merchantable	No. 3 Common	No. 4 Common	Green [1]	Dry [2]
	Per cent	*Per cent*	*Per cent*	*Dollars*	*Dollars*
9	60. 8	35. 8	3. 4	23. 25	22. 55
10	60. 8	35. 4	3. 8	23. 22	22. 52
11	60. 8	35. 0	4. 2	23. 20	22. 50
12	60. 9	34. 6	4. 5	23. 19	22. 49
13	60. 9	34. 2	4. 9	23. 16	22. 47
14	61. 0	33. 8	5. 2	23. 15	22. 46
15	61. 2	33. 2	5. 6	23. 14	22. 45
16	61. 3	32. 9	5. 8	23. 14	22. 45
17	61. 7	32. 4	5. 9	23. 17	22. 47
18	61. 8	32. 1	6. 1	23. 17	22. 47
19	62. 1	31. 6	6. 3	23. 18	22. 48
20	62. 5	31. 0	6. 5	23. 20	22. 50
21	62. 7	30. 8	6. 5	23. 22	22. 52
22	63. 1	30. 2	6. 7	23. 24	22. 54
23	63. 4	29. 8	6. 8	23. 26	22. 56
24	63. 6	29. 4	7. 0	23. 27	22. 57
25	64. 0	29. 0	7. 0	23. 30	22. 60

[1] Dry value based on volume when green and on the following prices f. o. b. shipping point: Merchantable, $27; No. 3 Common, $18; No. 4 Common, $11.50.
[2] Dry value was obtained by reducing the green value 3 per cent to cover the loss caused by degrade and shrinkage during drying.

In all comparisons of lumber values the value of the lumber when in a dry condition has been used although the lumber was graded when in a green condition. The percentage of upper grades in lumber in a green condition is higher than in seasoned lumber because any defects due to drying have not appeared. Therefore, a reduction of 5 per cent in value for sugar maple and yellow birch and 3 per cent for eastern hemlock from the average value of the lumber in a green condition has been made. This reduction is not based on comprehensive tests, because they are not available, but is based on judgment and merely represents the best estimate obtainable.

SUGAR MAPLE

In sugar maple, for example (Table 12), logs 8 inches in diameter saw out no FAS.[8] They have, however, a large percentage of No. 3 Common with the result that the lumber from these logs at the 1925–26 prices was worth only $21.51 a thousand board feet. On the other hand, logs 20 inches in diameter yield over 28 per cent FAS and Selects, and in consequence the lumber was worth $46.34 a thousand board feet. Similarly, lumber produced from sugar maple trees 9 inches in diameter (Table 13) was worth only $21.44 per thousand board feet, while that from trees 25 inches in diameter was worth $40.59 per thousand board feet, because of the higher grades of lumber obtainable from the larger trees.

YELLOW BIRCH

The grades and value of lumber from yellow birch logs and trees show the same relative trend as in sugar maple. (Tables 14 and 15.)

GRADES OF SUGAR MAPLE AND YELLOW BIRCH COMPARED

There is, however, considerable difference both in quality and value of the lumber obtainable from yellow birch and sugar maple logs of the same size. In yellow birch high-grade lumber can be obtained from smaller logs and trees and in greater quantities than from sugar maple. Table 18 is a direct comparison of the average grades and value of lumber from 14-inch logs of the two species and clearly brings out this point.

TABLE 18.—*Comparison of the average grades and value of lumber from 14-inch logs of yellow birch and sugar maple*

Species	Percentage of lumber of grade—					Value per thousand feet, board measure, dry lumber
	FAS	Select	No. 1 Common	No. 2 Common	No. 3 Common	
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Dollars*
Sugar maple	7.6	6.6	23.0	15.9	46.9	35.18
Yellow birch	9.8	7.5	22.2	17.6	42.9	41.15

EASTERN HEMLOCK

The grades of lumber from eastern hemlock logs and trees of different diameters (Tables 16 and 17) follow a different trend than

[8] Firsts and Seconds—a combined grade of the two upper grades of hardwoods.

that indicated in the hardwoods. The size of the eastern hemlock logs only moderately affects the amount of lumber that falls in the upper grades. An eastern hemlock log 8 inches in diameter contains about 61 per cent merchantable lumber (50 per cent No. 1 Common and 50 per cent No. 2 Common), whereas a log 20 inches in diameter contains 66 per cent merchantable lumber, or an increase of only 5 per cent. The increase in the high grades of lumber for the same diameter classes of either sugar maple or yellow birch is from two to three times as great as that from eastern hemlock. The grades in the hardwoods and eastern hemlock are, of course, not closely comparable, yet this comparison shows that the advantage of milling large logs over small logs is not so apparent in hemlock as in the hardwoods. Moreover, this comparison indicates that small eastern hemlock logs, on the basis of the value of the final product, can be handled to a better advantage than small hardwood logs.

LUMBER VALUE AND PRODUCTION COST COMPARED

LOG-RUN LUMBER VALUE AND PRODUCTION COST

The average value of the lumber, weighted according to the volume in each diameter class and the proportion of each species in the stand (Table 4), is $33.08 per thousand feet, board measure.

The average production cost was $23.87 a thousand feet, board measure (p. 21). Subtracting the cost of production, when all trees 9 inches and larger in diameter are cut, from the lumber value leaves $9.21 per thousand board feet to cover the cost of stumpage and to provide a margin for profit and risk.

LUMBER VALUE AND PRODUCTION COST FOR LOGS AND TREES OF DIFFERENT DIAMETERS

Frequently it is desirable to know the spread between the production cost and the lumber value for trees and logs of different diameters. For this reason the cost of producing lumber (exclusive of permanent improvements, woods supervision, general expense, taxes, and insurance on logs) and its value by diameter classes for logs and trees, all species together, is given in Tables 19 and 20.

These tables show that logs must be somewhat greater than 9 inches in diameter inside the bark and trees must be about 11½ inches in diameter breast high before the lumber obtained from them is worth more than the cost of producing it, not including the charges for permanent improvements, general expense, supervision, taxes, and insurance on logs.

TABLE 19.—*Lumber production cost*[1] *per thousand board feet, lumber tally, and value of lumber for logs of different diameters of all species studied*

[Includes items that vary with the size of log or are constant per thousand board feet]

Top diameter inside bark (inches)	Logging cost[1]	Milling cost	Total lumber production cost	Value of dry lumber	Difference between total lumber production cost and value of dry lumber
	Dollars	*Dollars*	*Dollars*	*Dollars*	*Dollars*
7	11.55	15.12	26.67	21.09	−5.58
8	10.50	15.57	26.07	22.04	−4.03
9	9.46	14.94	24.40	23.90	−.50
10	8.57	14.20	22.77	26.22	+3.45
11	7.83	13.48	21.31	28.76	7.45
12	7.21	13.02	20.23	31.27	11.04
13	6.70	12.74	19.44	33.64	14.20
14	6.33	12.49	18.82	35.58	16.76
15	5.99	12.29	18.28	37.63	19.35
16	5.79	12.06	17.85	39.50	21.65
17	5.62	11.80	17.42	41.16	23.74
18	5.53	11.50	17.03	42.40	25.37
19	5.45	11.24	16.69	43.41	26.72
20	5.40	10.12	15.52	38.98	23.46
Log run	7.10	12.82	19.92	33.08	13.16

[1] Excluding permanent improvements, supervision, general expense, taxes, and insurance on logs.

TABLE 20.—*Lumber production cost*[1] *per thousand board feet, lumber tally, and value of lumber for trees of different diameters of all species studied*

[Includes items that vary with the size of tree or are constant per thousand board feet]

Diameter breast high (inches)	Logging cost[1]	Milling cost	Total lumber production cost	Value of dry lumber	Difference between total lumber production cost and value of dry lumber
	Dollars	*Dollars*	*Dollars*	*Dollars*	*Dollars*
9	11.29	15.45	26.74	22.08	−4.66
10	10.71	15.15	25.86	22.93	−2.93
11	10.10	14.90	25.00	23.95	−1.05
12	9.51	14.57	24.08	25.08	+1.00
13	8.98	14.27	23.25	26.31	3.06
14	8.48	13.92	22.40	27.62	5.22
15	8.01	13.58	21.59	28.90	7.31
16	7.67	13.31	20.98	30.19	9.21
17	7.28	13.09	20.37	31.46	11.09
18	7.00	12.87	19.87	32.74	12.87
19	6.72	12.66	19.38	33.85	14.47
20	6.46	12.52	18.98	35.01	16.03
21	6.32	12.38	18.70	36.24	17.54
22	6.15	12.21	18.36	37.31	18.95
23	6.02	12.04	18.06	38.40	20.34
24	5.89	11.91	17.80	39.39	21.59
25 and up	5.51	11.41	16.92	38.51	21.59
Log run	7.10	12.82	19.92	33.08	13.16

[1] Excluding permanent improvements, supervision, general expense, taxes, and insurance on logs.

In actual practice it is impossible to distribute the cost of permanent improvements by tree-diameter classes, as was done with the direct charges, since such expenditures, although constant per acre, vary per thousand board feet in accordance with diameter cutting limits; that is, with the total amount of timber removed from the land. Often, however, it is desirable to know the minimum size of tree that will pay its way. One method of arriving at an answer to this question is to allot arbitrarily to each diameter class the average cost per thousand board feet of permanent improvements, supervision, taxes, insurance, and general expense for the stand as a whole. When these costs amounting to $3.95 per thousand board feet, lumber tally, are taken into account the differences for individual diameter classes, which are given in the last column of Tables 19 and 20, show that in order to pay its way a log must be about 10¼ inches in diameter and a tree about 13½ inches in diameter breast high.

APPLICATION OF RESULTS TO SELECTIVE LOGGING

CUTTING TO A DIAMETER LIMIT

With a knowledge of the volume, value, and cost of producing lumber by diameter classes, it is possible to compute the results when only a certain proportion of the trees in a stand are cut. Removing only a part of the stand is exactly what takes place under selective logging, the chief aim of which is to remove at the lowest cost the greatest value with the least volume and at the same time keep the stand in a healthy growing condition.

EFFECT OF DIFFERENT DIAMETER CUTTING LIMITS ON THE VARIOUS COST FACTORS OF LUMBER PRODUCTION

Before considering cutting limits, it is worth while to note how the various factors in lumber production are affected when the smaller trees are not cut. (Table 21.) It has been shown that, when all trees 9 inches in diameter and larger are cut, the direct logging cost is $7.10, the milling $12.82, and the permanent improvements $3.95, making a total of $23.87 per thousand feet, board measure. Under like conditions the lumber is worth $33.08 per thousand board feet. Supposing, however, that only trees 13 inches and larger in diameter, instead of all trees 9 inches and larger, are cut, then the direct woods costs decrease 36 cents per thousand board feet, the milling cost declines 22 cents, while the value of the lumber increases $1.01, making a total gain of $1.59 per thousand board feet. Owing to a decrease in the amount of timber cut per acre, however, the permanent improvement costs have increased 51 cents per thousand board feet so that the net gain due to leaving all trees of 12-inch and smaller diameters on the ground is $1.59 minus 51 cents or $1.08 a thousand board feet. Similar calculations apply to all the items in the last column of Table 21.

TABLE 21.—*Effect of cutting to different diameter limits upon various cost factors per thousand feet, board measure, of lumber production*

Cutting to a diameter limit, breast high (inches)	Decrease in production costs		Increase in lumber value	Total increase in returns	Increase in cost of permanent improvements	Net increase in profits
	Woods (excluding permanent improvements)	Mill				
	Dollars	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*
9 and up	0.00	0.00	0.00	0.00	0.00	0.00
10 and up	.03	.01	.08	.12	.04	.08
11 and up	.10	.06	.29	.45	.13	.32
12 and up	.21	.13	.61	.95	.28	.67
13 and up	.36	.22	1.01	1.59	.51	1.08
14 and up	.46	.32	1.47	2.25	.77	1.48
15 and up	.60	.42	1.97	2.99	1.13	1.86
16 and up	.72	.52	2.50	3.74	1.60	2.14
17 and up	.85	.63	3.05	4.53	2.19	2.34
18 and up	.97	.74	3.61	5.32	2.94	2.38
19 and up	1.09	.84	4.13	6.06	3.89	2.17
20 and up	1.20	.94	4.62	6.76	5.04	1.72

Since the hardwood-hemlock forest is ideally adapted to selective logging the question arises, what diameter limit of cutting yields the highest profit per thousand board feet and per acre?

CUTTING TREES 18 INCHES IN DIAMETER AND LARGER GIVES THE HIGHEST RETURN PER THOUSAND BOARD FEET

For the conditions studied, the highest profit per thousand board feet occurs when only trees 18 inches in diameter and larger are cut. (Table 22.) This means that the lumberman who plans on a second cut makes the most money from what he cuts when he leaves uncut all trees below 18 inches in diameter.

TABLE 22.—*Total cost of production and returns per thousand feet, board measure, by cutting to different diameter limits*

Cutting to a diameter limit, breast high (inches)	Production cost			Value of lumber	Difference between total production cost and value of lumber [1]
	Woods	Mill	Total		
	Dollars	*Dollars*	*Dollars*	*Dollars*	*Dollars*
9 and up	11.05	12.82	23.87	33.08	9.21
10 and up	11.06	12.81	23.87	33.16	9.29
11 and up	11.08	12.76	23.84	33.37	9.53
12 and up	11.12	12.69	23.81	33.69	9.88
13 and up	11.20	12.60	23.80	34.09	10.29
14 and up	11.36	12.50	23.86	34.55	10.69
15 and up	11.58	12.40	23.98	35.05	11.07
16 and up	11.93	12.30	24.23	35.58	11.35
17 and up	12.39	12.19	24.58	36.13	11.55
18 and up	13.02	12.08	25.10	36.69	11.59
19 and up	13.85	11.98	25.83	37.21	11.38
20 and up	14.89	11.88	26.77	37.70	10.93

[1] Available for stumpage and profit.

The following example illustrates the manner in which the results in this table were calculated:

It is desired to compute the woods cost when only trees 12 inches in diameter and larger are cut. When 100 per cent of the stand (trees 9 inches and larger in diameter) is cut, the logging cost is $11.05 (p. 7). Table 3 shows that the 9-inch diameter class contains 0.7 per cent, the 10-inch class 2.0 per cent, and the 11-inch class 3.2 per cent of the entire stand cut, thus making a total of 5.9 per cent. Therefore, if only the trees 12 inches in diameter and larger are cut, only 94.1 per cent of the total volume is removed. The direct log-run cost of logging under this diameter limit is determined by subtracting from the total direct cost of $7.10 (Table 20) the cost of cutting these smaller diameters and dividing the result by 94.1, the percentage of the total volume removed. The computation follows:

0.7 per cent×11.29 (Table 20)=	$0.079
2.0 per cent×10.71 (Table 20)=	.214
3.2 per cent×10.10 (Table 20)=	.323
Total=	.616

$$\frac{\$7.10-\$0.616}{94.1}=\$6.89$$ per thousand board feet, lumber tally. To this must be added taxes and insurance on logs, which amount to 20 cents, gross log scale (p. 7), or 17 cents lumber tally, making a total of $7.06. There remains the cost of permanent improvements, general expense, and supervision. The log-run cost, when all timber 9 inches in diameter and larger is cut, is $3.78 lumber tally. If only trees 12 inches and larger are cut the overrun declines to 17.1 per cent, with the result that the other costs become $3.82 instead of $3.78. But only 94.1 per cent of the stand was cut, so these costs will increase ($3.82—94.1) to $4.06 per thousand feet, board measure. By adding to this figure the direct costs of $7.06, the total logging cost becomes $11.12 per thousand board feet when all trees below 12 inches in diameter are left uncut. The other figures in Table 22 were computed similarly.

Reference to Table 22 shows that the total production cost per thousand feet, board measure, varies but little with the change in cutting limits until a diameter of 16 inches is reached. Up to this diameter the decreased cost of felling, bucking, milling, and the like, is just about offset by the increased costs of permanent improvements, general expense, and woods supervision. Above this diameter for the next 2 inches the total production increases moderately. However, the quality of the lumber is steadily improved, so that the increasing production cost is more than offset by the greater value of the lumber until a diameter limit of 18 inches is reached. This is shown by the steady increase in the difference between production cost and the value of the lumber from $9.21, corresponding to a diameter cutting limit of 9 inches, to $11.59 at 18 inches. Above this point the difference decreases, because in cutting to the larger diameter limits the volume per acre is so reduced as to greatly increase the cost per thousand board feet of permanent improvements, general expense, and woods supervision.

CUTTING TREES 12 INCHES IN DIAMETER AND LARGER GIVES THE HIGHEST RETURN PER ACRE

The greatest profit per acre was found to occur on the standard lumber operations when only trees 12 inches in diameter and larger were cut. (Table 23.) This means that the lumberman who does not plan on a second cut makes the most money from his operation when he leaves uncut all trees below 12 inches in diameter. In addition, the cut-over land has a higher potential value, because the nucleus for a future cut remains on the ground and the presence of even small trees adds to its value for recreational purposes. (Fig. 3.)

TABLE 23.—*Effect of different cutting limits on the returns per acre*

Cutting to a diameter limit, breast high (inches)	Amount cut per acre	Difference between total production cost and value of lumber per thousand feet, board measure	Total returns per acre [1]	Cutting to a diameter limit, breast high (inches)	Amount cut per acre	Difference between total production cost and value of lumber per thousand feet, board measure	Total returns per acre [1]
	Board feet	*Dollars*	*Dollars*		*Board feet*	*Dollars*	*Dollars*
9 and up	15,851	9.21	145.99	15 and up	12,554	11.07	138.97
10 and up	15,740	9.29	146.22	16 and up	11,555	11.35	131.15
11 and up	15,423	9.53	146.98	17 and up	10,478	11.55	121.02
12 and up	14,916	9.88	147.37	18 and up	9,352	11.59	108.39
13 and up	14,250	10.29	146.63	19 and up	8,258	11.38	93.98
14 and up	13,457	10.69	143.86	20 and up	7,228	10.93	79.00

[1] Cost of stumpage and margin for profit and risk must be paid out of these returns.

FIGURE 3.—Selective logging leaves the land covered with trees, which adds to the value of the land for recreational purposes

These results are conservative, since they are based on the assumption that woods supervision and general expense increase under selective logging. If, instead, these costs were considered as varying with the output of the woods crews, they would decrease as the diameter cutting limit increased. In such an event the difference between the returns per acre when cutting all merchantable trees and when cutting only trees 12 inches in diameter and larger would be about twice as large as shown. Furthermore, the total cost of permanent improvements has been charged to the first cut. Under selective logging the established railroad grades could be used, in part at least, for each successive cut, and in this way cheapen the production cost.

Under different conditions, diameter cutting limits other than 12 inches, which give the greatest return per acre, or 18 inches, which give the greatest return per thousand board feet, may be more satisfactory. Such limits can be set up by the operator with the aid of the information in this bulletin. It is not the purpose, however, to convey the idea that these are the only two cutting limits that need to be taken into account when setting up a cutting plan for a stand of timber.

AN ACTUAL EXAMPLE OF SELECTIVE LOGGING

An example of selective logging, in the Upper Peninsula of Michigan, near Marquette, may be cited (*24*). In a stand of timber which averaged 6,350 board feet net log scale per acre, 2,250 board feet, or about 35 per cent, was removed in selective logging. In all, 45,000 board feet was removed from 20 acres, and in addition 160 cords of chemical wood was cut from the defective portions of the trees, from the tops, and from the small cull trees which were considered not worth retaining in the stand. The stand averaged 190 trees per acre between 3 and 38 inches in diameter. On an average about eight trees were cut to the acre, and the diameter of the trees cut corresponded roughly to a diameter limit of 22 inches breast high.

The logging was done by a contractor at a cost, including felling, hauling, and loading on the cars, of $10.50 per thousand board feet. The cost of cutting, hauling, and loading chemical wood, which was disposed of at a stumpage price of 50 cents a cord, was $4 a cord.

On the entire tract only 89 trees were knocked down by felling, and only 3 of these were 12 inches or over in diameter. The cutting demonstrated that selective logging can be carried on under practical logging conditions without appreciable damage to the trees which are to be left for the next cutting. It has shown further that the cost of the method is not prohibitive; that the cost per thousand board feet compares very favorably with the usual large-scale operation where the forest is clear cut. Since the tops and the large limbs were cut into chemical wood down to 3 inches, there was no expense for slash disposal.

A most striking result of selective logging in this instance is that, because of the high quality of the product (fig. 4, C), more than half of the value of the stand was removed and yet only one-third of the volume. The average value of hardwood logs cut in ordinary logging operations during the winter of 1926–27 was about $19 a thousand feet on the cars and in some localities even less. Of these logs cut under selective logging the maple logs were worth $27.30 a thousand feet and the birch $39.31. Since there were cut 6,000 feet of birch logs and 39,000 feet of maple, the average value of the logs cut on the 20 acres was $28.93 a thousand feet. Had the entire stand been cut the value of the logs at $19 a thousand feet would have been $120.65 an acre. The value of only 35 per cent of the volume in logs taken from the largest trees was about $65 an acre.

The chemical wood, produced from the tops and defective portions of the trees and from smaller defective trees, aggregated 160 cords and brought in an additional $80, or $4 an acre.

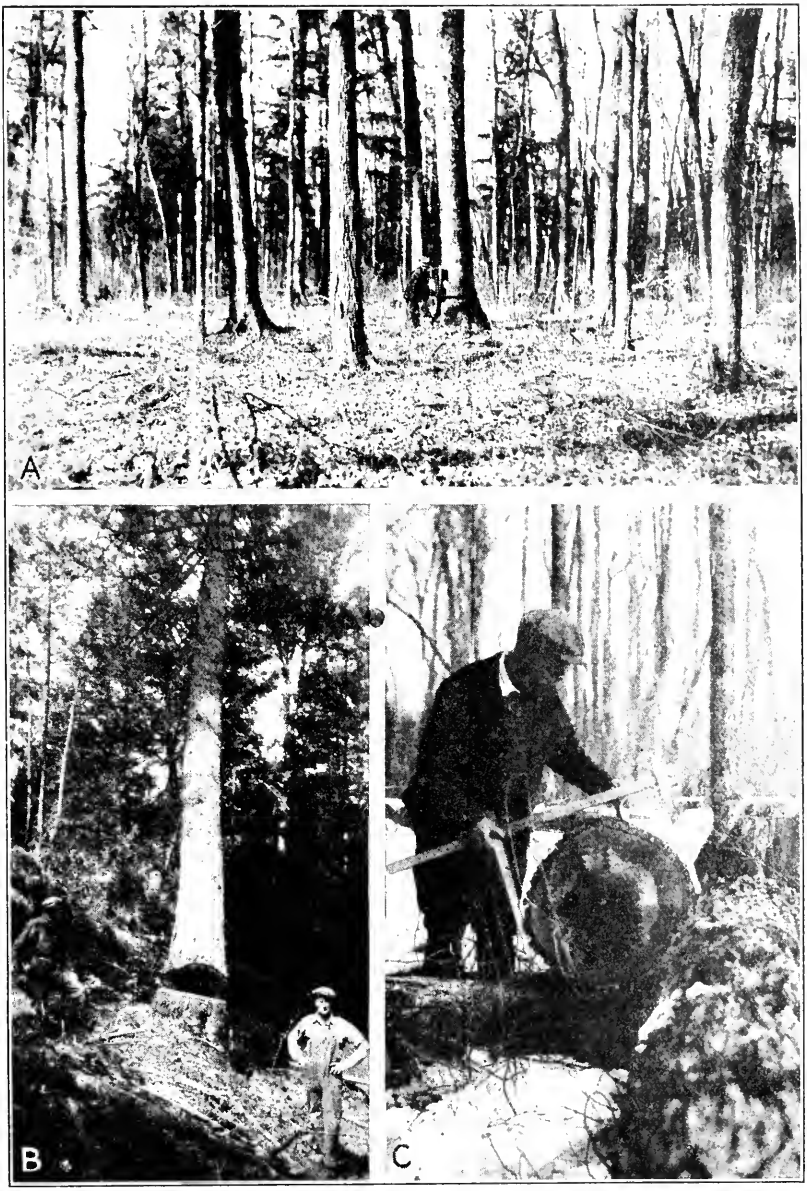

FIGURE 4.—Selective logging removes the larger trees and leaves the small thrifty ones on the ground to grow; A, Marking the trees to be cut under selective logging; B, felling a large eastern hemlock; C, the kind of logs removed under selective logging

The proceeds and the logging cost on the 20 acres, not including charges on the investment or any other carrying charges, were as follows:

Receipts from selective logging

45,000 feet of logs, at $28.93	$1,301.85
Cost of logging, at $10.50	472.50
Receipts from logs after deducting logging cost	829.35
Receipts from 160 cords chemical wood, at 50 cents stumpage	80.00
Total receipts from 20 acres	909.35
Receipts per acre	45.47

In another 20 years the 41 trees per acre between 12 and 22 inches in diameter left under selective logging will increase 2 to 4 inches in diameter. This will more than make up for the 2,250 feet removed in the selective logging. In 20 years the growth of the trees now left will bring the stand back to its original volume, and it should be possible to make another selective cut at that time of as high-quality timber and to get for it at least a similar return. With selective logging, then, the forest will be continuously productive, bringing in, according to this example, approximately $50 an acre every 20 years, or an average of $2.50 an acre a year, excluding carrying charges.

This selective cutting, although only one year's cut and by no means conclusive, opens up perspectives and possibilities worth considering.

ADVANTAGES OF SELECTIVE LOGGING

REMOVAL OF THE MOST VALUE WITH THE LEAST VOLUME

One of the most practical aspects of selective logging is that under such practice it becomes possible to take out a large part of the value of the stand in the form of larger trees and yet remove a smaller proportion of the total volume. This point is brought out in the actual example of selective logging just given and is substantiated by figures obtained in this investigation, where cutting 34 per cent of the volume (trees 22 inches in diameter and larger) removed over 39 per cent of the total value of the stand for lumber; cutting 66 per cent of the total volume (trees 17 inches and larger) removed 72 per cent of the total value.

Because the higher values in the forest are taken under selective logging, one of the chief financial obstacles to the practice of forestry is greatly reduced; namely, the carrying of large investments in virgin timber.

TIMBER HAS A HIGHER VALUE UNDER SELECTIVE LOGGING

The value of timber for the production of lumber under selective logging increases until about an 18-inch diameter limit of cutting is reached. (See last column Table 22.) Above an 18-inch diameter limit the value declines because the increased cost of permanent improvements more than offsets the reduction in production costs. Timber value as here used is the difference between the total production cost plus 15 per cent as a margin for profit and the selling price of the lumber. Table 24, which is based on the figures obtained in this investigation, shows that if all trees 9 inches in diameter and larger are cut the timber (stumpage) is worth $7.10 a thousand board feet net log scale, but if only trees 20 inches in diameter and larger are cut the timber has a value of $8.33 a thousand board feet.

TABLE 24.—*Comparative value of timber for standard lumber when cutting to different diameter limits*

Cutting limit, diameter breast high (inches)	Value of stumpage per thousand feet, board measure, lumber tally	Value of stumpage per thousand feet, board measure, net log scale	Cutting limit, diameter breast high (inches)	Value of stumpage per thousand feet, board measure, lumber tally	Value of stumpage per thousand feet, board measure, net log scale
	Dollars	*Dollars*		*Dollars*	*Dollars*
9 and up	5.63	7.10	15 and up	7.47	9.22
10 and up	5.71	7.19	16 and up	7.72	9.48
11 and up	5.95	7.47	17 and up	7.86	9.60
12 and up	6.31	7.90	18 and up	7.83	9.52
13 and up	6.72	8.37	19 and up	7.51	9.09
14 and up	7.11	8.82	20 and up	6.91	8.33

LOGS HAVE A HIGHER VALUE UNDER SELECTIVE LOGGING

Most of the cut under selective logging is made up of large trees, hence the logs from them yield higher grades of lumber and must therefore have a higher value. Information on the value of logs of different sizes is helpful in determining whether they are more profitable for lumber, veneer, or other products.

By subtracting from the value of the lumber, the milling cost plus 15 per cent, and by correcting for overrun, the value of the logs is obtained. These values are given in Table 25.

TABLE 25.—*Relative value of logs of different sizes and species, and of all species together for standard lumber*

Top diameter inside bark (inches)	Logs per thousand board feet	Value of logs per thousand board feet, net log scale, of— Sugar maple	Yellow birch	Eastern hemlock	All species studied
	Number	*Dollars*	*Dollars*	*Dollars*	*Dollars*
7	42	0.73	4.37	16.19	5.70
8	31	4.43	8.72	15.89	5.99
9	24	8.36	13.01	15.62	9.35
10	19	12.38	17.24	15.39	13.27
11	16	16.26	21.24	15.22	17.26
12	13	19.58	25.25	15.34	20.70
13	10	22.54	28.66	15.53	23.62
14	9	25.14	32.44	15.72	25.91
15	7	27.72	36.05	15.81	28.41
16	6	30.16	39.70	15.87	30.58
17	5	32.46	43.50	16.05	32.64
18	5	34.54	47.56	16.24	34.26
19	4	36.25	52.09	16.41	35.54
20	4	37.65	57.43	16.58	31.93

EARLY SECOND CUT

How soon a lumberman may return for a second cut will depend on (1) the number, size, and species of trees left, and (2) on the site (soil quality and growing conditions). In a recent study (25) made in Wisconsin, the annual growth per acre in partially cut stands ranged from 102 to 240 board feet. The average annual growth for 17 plots, aggregating close to 400 acres, was in round figures 145 board feet. The detailed results of this study are contained in Table 31 (p. 44) from which an owner of timber may make a rough estimate of the rate of growth that may be obtained from mixed hardwood timber left standing after partial cutting and the number of years that must elapse before a definite amount may again be cut. To illustrate: If a light, partial cutting of 50 per cent of the volume is made from a stand averaging 13,000 board feet, it will probably require about five years to grow 1,000 board feet, or 15 years to grow 3,000 board feet. If from 75 to 85 per cent of the merchantable volume is removed, it may take 7 years to replace 1,000 board feet by growth or 21 years for 3,000 board feet. If still heavier cutting is made, the time required to produce a second merchantable cut is further extended. Being average figures, Table 31 applies more accurately to large tracts than to small ones.

IMPROVEMENT OF THE FOREST

Care must be used in designating trees to be removed under selective logging. Clinging rigidly to a diameter limit of cutting may not produce the best results since in order to obtain the maximum growth of trees left in the woods, some trees above or below the cutting limit may be taken or left, depending on the soundness, thrift, growth rate, species, and form of the timber, danger from windfall, and the needs of the young growth on the ground. Trees below the diameter limit might be cut very properly if their removal is necessary to thin out a thick patch, while trees above the cutting limit might be left if they stand in openings.

The average quality of lumber from the first cutting is often of lower quality than that from later cuttings, because the owner should remove a number of defective and poorly formed trees along with the better trees. These poor trees reduce the average quality of the lumber slightly, but by taking them out the remaining good trees have a better chance to increase their growth rate and in this way offset the loss. This point should be kept in mind when considering the results of selective cutting.

The results of two operations in the Lake States have shown that it is entirely practicable to log selectively without seriously damaging the trees left on the ground. This is important since it is necessary to save the small trees and leave the forest in good condition in order to get the best possible growth after each cutting.

Selective logging makes it possible for the owner to favor the species he desires to grow, whereas under clear cutting, even with fire protection, there is no assurance of the regrowth of the desired species. Instead of sugar maple and yellow birch there may be aspen, red maple, and other less desirable species, and quite probably the new stand will be either too thick or too thin.

Selective logging not only removes the most valuable part of the stand but at the same time improves the growth of the remaining timber and affords opportunity to encourage the growth of species that are wanted. (Fig. 4, B.)

SOLVING THE SMALL-LOG PROBLEM

Small logs are produced from small trees and from the tops of large trees. Selective logging reduces the proportion of small logs, because the small trees are not cut. Cutting small trees is avoidable and is inconsistent with good forest practice. Leaving them involves no waste in utilization, but, on the contrary, it actually contributes to the increased growth and perpetuation of the stand. The small trees (8 inches to 14 inches in diameter) are just at the period in their development where the growth is rapid, and if left they may be considered an asset. On the other hand, if the logs from these small trees are cut into lumber they become a liability and must be carried at the expense of the large logs.

The top logs from large trees, however, are unavoidable and can be viewed from different financial angles than the logs from small trees. Whether these top logs are utilized or not, the tree itself must be felled in order to get the large logs, and all improvements for effective logging and milling must be provided. Once cut down these logs are of no value to the forest, but are a liability from a fire hazard and sanitation standpoint. Under such conditions it should be permissible not to charge the top logs obtained from large trees with the costs of felling, permanent improvements, and depreciation. Under this method of cost accounting, top logs of 8 or 9 inches in diameter show a slight profit. These costs obtain where the small logs are sawed into lumber with the same machinery as that used for cutting large logs. If top logs are cut by special equipment into products other than lumber, such as dimension stock and ties, they will probably show a much better profit.

FIRE HAZARD REDUCED UNDER SELECTIVE LOGGING

A forest cut selectively is not so great a fire hazard as a clear-cut area. The comparatively small number of trees that are cut per acre, even when the tops are not utilized for chemical wood, do not make heavy slash and such slash is separated by green standing timber. Moreover, the conditions are less favorable for a fire to continue to burn because the humidity of the air is higher, the temperature of the air and soil lower, and the wind movement considerably less than in a clear-cut forest. (Fig. 5.) Actual observations conducted on the climatic factors within and without a hardwood forest in the Lake States show that the maximum air temperatures during July and August were from 4 to 5 degrees higher in an unforested area than in a forested area and the relative humidity of the air for the same months was between 6 and 7 per cent less in the unforested area than in the forested area. The wind movement in the unforested area for the summer season averaged 2.7 miles per hour and only 0.6 mile during the same period in the forest. During the warm days of the summer, the temperature of the soil in the open was from 8 to 10 degrees higher than in the forest.

It is generally known from experience that the danger from fires during the period between the middle of July to the end of October is especially great when the relative humidity of the air falls below 50 per cent. In the unforested area studied there were 14 days during this period when the relative humidity fell below 50 per cent, and only 6 days when the relative humidity of the air in the forest was below this danger point, which indicates that the relative danger from fire in a forest cut selectively is not great.

In the fall the herblike vegetation in the forest is still green, while in the open all the grass has been killed by frost and it is readily inflammable. In the early spring the dead vegetation in the open dries earlier and is readily inflammable at a time when the forest is still moist.

For the foregoing reasons the fire hazard in a forest cut selectively is much less than in a forest cut clear with heavy slashings left on the ground.

FIGURE 5.—Areas cut under selective logging and under clear cutting: A, Selectively logged area with thrifty young trees left on the ground to grow into a future cut; B, a clear-cut area with heavy slashings

BUSINESS AND COMMUNITY STABILIZED

Selective logging prolongs the life of a lumber operation and with adequate acreage will make it permanent by providing a continuous supply of timber. On the other hand, clear cutting of all merchantable timber with no provision for regrowth involves heavy depreciation charges against the plant, railroad, and other permanent improvements with a consequent increase in the cost of doing business. Moreover, it prevents the development of a permanent community. With selective logging the reverse is true. The life of the operation is prolonged or made permanent, and as a result depreciation charges are reduced. A feeling of permanency is created in the community with the result that schools, churches, and business may be safely established on a substantial basis.

Selective logging on forest areas eliminates the cut-over land problem. Further, selective logging goes far toward a satisfactory solution of the tax problem, for selectively cut lands receive favorable consideration under the forest crop laws in both Michigan and Wisconsin.

SELECTIVE LOGGING—A PROBLEM FOR EACH INDIVIDUAL OPERATOR

Immediate financial considerations as well as indirect advantages indicate the desirability of a change of logging methods in the Lake States. Selective logging seems to be the logical answer. The figures in this bulletin indicate that operators who are producing only lumber and who have no thought of making their operation permanent should refrain from cutting trees under 12 inches in diameter. By so doing they make the highest profit per acre from their operation and at the same time increase the value of their cut-over land by leaving small trees uncut.

The establishment of a diameter limit for the operator who wants to practice selective logging with a view to permanent operation is not so simple. What diameter limit of cutting he chooses will depend largely on the grade of logs and lumber he wishes to produce, the size and character of his timber holdings, the time he can allow between successive cuts, and his ability or desire to invest in future growth. No attempt is made to set down a definite cutting limit. From the facts presented here each individual owner who wishes to go into selective logging will have to make an analysis of his own operation and then decide for himself the diameter limit of cutting that best meets his needs. For example, one operator in the Lake States after analyzing his operation has decided that cutting all trees 22 inches in diameter and larger is the most profitable for him. (Fig. 4, C.) Another owner with different conditions might decide on a higher or lower cutting limit. For the operations investigated a diameter cutting limit of 18 inches gave the highest return per thousand board feet.

CONCLUSIONS

Based on this investigation, the comparative results under clear cutting and selective cutting on lumber operations in the hardwood-hemlock type in the Lake States may be summarized as follows:

For the tracts studied and with the cost distribution used here, the highest profit per thousand board feet occurs when only trees 18 inches in diameter and larger are cut. If the owner has a good supply of timber on hand and is planning on a second cut, the 18-inch diameter cutting limit will net him the highest profit for each thousand feet of lumber produced and yet leave enough timber (41 per cent of the original volume) on the ground to provide a second cut of large timber within a reasonable time.

The highest profit per acre is obtained when only trees 12 inches in diameter and larger are cut. This means that the lumber operator, even if he has no thought of a second cut but wants to remove in one logging all the merchantable timber, really loses money by cutting trees less than 12 inches in diameter.

A change from clear cutting (all trees 9 inches in diameter and up) to cutting to a diameter limit does not increase the cost of lumber production until a diameter limit of about 16 inches is reached. Above this point the production cost begins to rise because the cost of permanent improvements becomes increasingly greater and more than offsets the total effect of the cheapened direct logging and milling costs and the increased value of the lumber.

The most desirable diameter cutting limits will vary from one operation to another according to the distribution of trees by diameter classes in the stand, prevalence of a particular species, price of lumber, and management plans adopted by the operator. The cutting limits shown in this bulletin apply to the conditions studied. In so far as these operations are representative of the region, the diameter cutting limits may be considered to apply to the region as a whole.

Selective logging helps to solve the problem of the small log. By leaving uncut the small trees the number of small logs is greatly reduced.

Under selective logging, the annual growth per acre will range from 102 to 240 board feet, depending upon (1) the number, size, and species of trees left at the time of cutting, and (2) on the site (soil quality and growing conditions).

Under selective logging, it becomes possible to take out a large part of the value of the forest in the form of larger trees, and yet remove a smaller proportion of the total volume.

Since, as a general rule, only the larger trees are cut under selective logging, the logs from them yield higher grades of lumber and consequently lumber of higher value.

Selective logging is a means of improving the forest. By marking the trees for removal, the owner can favor the species that he wants to grow, instead of leaving entirely to nature the kind of trees that may come in after logging. (Fig. 4, A.)

A forest cut selectively represents much less of a fire hazard than a forest cut clear with heavy slashings left on the ground.

Selective logging prolongs the life of a lumber operation. It does away largely with the problem of cut-over land. It helps in the solution of the tax problem and contributes to the stability of the community in which the sawmill is located.

SUPPLEMENTARY INFORMATION

The tables which follow are for reference purposes and will be helpful in establishing satisfactory wage scales and in working out cutting practices for individual operations.

BASIS OF PAYMENT

The basis on which woods felling crews are paid has a marked effect on selective logging. A number of operators pay their log cutters a flat rate per linear foot. Quite naturally the cutters skin the land of all the small trees the company will accept. Sawing 8-inch logs requires nearly three times as much work a thousand board feet as sawing 24-inch logs, yet with the payment on a linear foot basis a sawyer's earnings per thousand board feet is 12½ times as great for 8-inch as for 24-inch logs. (Table 26.) Table 25 shows that based on the actual labor involved the payment for 8-inch logs per linear foot is about $0.007 or $3.35 a thousand board feet, instead of $5.50 a thousand board feet when based on the flat rate system. For 16-inch logs based on the actual labor involved, the payment is $0.017 a linear foot instead of $0.011, and it is $1.69 a thousand board feet instead of $1.11 as is the case with the flat-rate linear-foot basis.

Table 26.—*Cost of sawing for logs and trees when payment is based on actual labor involved and when based on a definite amount per linear foot for all species studied*

Top diameter inside bark (inches)	Cost of sawing per thousand board feet, gross scale at $0.011 per linear foot	Rate of payment for sawing— Logs: On basis of labor involved at average rate of $2.08 per thousand board feet and $0.011 per linear foot		Trees	
		Per linear foot	Per thousand board feet, gross scale	Diameter breast high (inches)	Per thousand board feet, gross scale
	Dollars	*Dollars*	*Dollars*		*Dollars*
6	9.78	0.0052	4.60	8	4.06
7	7.33	.0058	3.87	9	3.68
8	5.50	.0067	3.35	10	3.38
9	4.19	.0076	2.91	11	3.12
10	3.26	.0088	2.60	12	2.91
11	2.75	.0094	2.34	13	2.73
12	2.23	.0107	2.16	14	2.57
13	1.81	.0121	1.99	15	2.42
14	1.53	.0134	1.88	16	2.29
15	1.24	.0156	1.76	17	2.18
16	1.11	.0168	1.69	18	2.08
17	.95	.0187	1.62	19	1.99
18	.83	.0209	1.57	20	1.91
19	.73	.0228	1.52	21	1.85
20	.63	.0257	1.47	22	1.79
21	.58	.0272	1.43	23	1.74
22	.53	.0292	1.40	24	1.69
23	.47	.0323	1.37	25	1.64
24	.44	.0338	1.34	26	1.60
Log run	2.08	.0110	2.08	27	1.57
				28	1.53
				29	1.50
				30	1.48
				Log run	2.08

It is therefore evident that sawyers when paid at a flat rate of $0.011 a linear foot are penalized when cutting large logs and favored when cutting small logs. The sawyers are aware of this in a general way and as a result slaughter the small trees if given an opportunity.

It seems quite certain that the flat-rate system of payment has exerted more influence than is ordinarily recognized in bringing about clear cutting of the forest. The figures in Table 26 may be used to compute linear-foot payment that is fair to both the sawyer and operators. Such a method of payment is worth considering if an operator wishes to save his small trees.

DIRECT COST OF MILLING TREES OF DIFFERENT DIAMETERS AND SPECIES

Table 27 gives the cost of milling for trees of different species and diameters. The operator who does not have the same proportion of hardwoods and hemlock as found in this study can use the information in these tables to compute a weighted average cost of milling for his own operation.

VARIATION IN THE AMOUNT OF DEFECT

Defect varies both in the size of log and the species. (Table 28.) This information is valuable to the man who is buying logs.

TABLE 27.—*Cost of milling trees per thousand feet board measure, by diameter classes and species*

Diameter breast high (inches)	Sugar maple	Yellow birch	Eastern hemlock	Diameter breast high (inches)	Sugar maple	Yellow birch	Eastern hemlock
	Dollars	*Dollars*	*Dollars*		*Dollars*	*Dollars*	*Dollars*
9	16.27	16.75	11.29	18	13.05	13.05	9.51
10	15.75	16.14	11.09	19	12.87	12.83	9.31
11	15.37	15.67	10.90	20	12.75	12.66	9.12
12	14.98	15.19	10.70	21	12.62	12.53	8.96
13	14.58	14.70	10.51	22	12.48	12.40	8.76
14	14.18	14.27	10.30	23	12.36	12.27	8.62
15	13.80	13.83	10.10	24	12.27	12.18	8.52
16	13.54	13.54	9.91	25	12.18	12.10	8.43
17	13.27	13.26	9.71				

TABLE 28.—*Amount of defect by species and size of tree*

Diameter breast high (inches)	Sugar maple	Yellow birch	Eastern hemlock	Diameter breast high (inches)	Sugar maple	Yellow birch	Eastern hemlock
	Per cent	*Per cent*	*Per cent*		*Per cent*	*Per cent*	*Per cent*
7	3.6	6.2	1.0	15	5.4	10.0	8.5
8	3.8	6.4	2.9	16	5.7	10.9	9.0
9	4.0	7.0	4.4	17	6.3	11.8	9.5
10	4.3	7.5	5.4	18	7.0	12.4	9.5
11	4.8	8.1	5.4	19	8.0	12.8	9.5
12	5.1	8.4	5.8	20	8.8	12.9	9.6
13	5.3	8.9	6.7	Log run	5.5	9.5	7.9
14	5.1	9.7	7.9				

NET AND GROSS OVERRUN FOR LOGS AND TREES OF DIFFERENT DIAMETERS AND SPECIES

Tables 29 and 30 give the net and gross overrun for logs and trees of different diameters and species. This information is of interest to the lumberman who is buying logs and may be used by the operator who is computing diameter cutting limits for his own holdings.

TABLE 29.—*Gross overrun for logs and trees of different diameters and species*

Logs				Trees			
Top diameter inside bark (inches)	Gross overrun of—			Diameter breast high (inches)	Gross overrun of—		
	Sugar maple	Yellow birch	Eastern hemlock		Sugar maple	Yellow birch	Eastern hemlock
	Per cent	*Per cent*	*Per cent*		*Per cent*	*Per cent*	*Per cent*
7	46.3	29.5	64.0	9	40.0	28.7	64.0
8	10.1	26.5	52.5	10	37.3	26.8	59.2
9	34.0	23.4	42.5	11	34.7	25.0	54.5
10	28.9	20.5	34.0	12	32.1	23.3	50.0
11	24.3	17.6	28.5	13	29.6	21.5	45.5
12	20.7	15.0	24.2	14	27.2	19.7	41.2
13	17.8	12.5	20.2	15	25.0	18.0	36.0
14	15.7	10.2	16.5	16	22.8	16.3	33.0
15	14.0	8.5	13.5	17	20.8	14.7	29.5
16	12.3	6.5	11.0	18	18.9	13.1	26.0
17	10.5	4.5	10.0	19	17.3	11.7	23.0
18	8.6	3.0	9.5	20	16.0	10.3	20.5
19	6.5	2.0	9.0	21	14.6	9.0	18.5
20	4.4	1.5	8.5	22	13.4	7.8	16.5
Log run	19.1	11.4	22.4	23	12.1	6.6	14.8
				24	11.0	5.6	13.7
				25	9.8	4.6	12.8

TABLE 30.—*Net overrun for logs and trees of different diameters and species*

Logs				Trees			
Top diameter inside bark (inches)	Net overrun of—			Diameter breast high (inches)	Net overrun of—		
	Sugar maple	Yellow birch	Eastern hemlock		Sugar maple	Yellow birch	Eastern hemlock
	Per cent	*Per cent*	*Per cent*		*Per cent*	*Per cent*	*Per cent*
7	51.7	38.0	65.7	9	44.4	37.4	69.5
8	45.7	35.2	57.0	10	41.8	35.8	64.8
9	39.5	32.7	49.0	11	39.5	34.2	60.2
10	34.7	30.2	41.6	12	37.2	32.6	55.7
11	30.6	28.0	35.8	13	35.1	31.1	51.4
12	27.2	25.5	31.8	14	33.0	29.6	47.4
13	24.4	23.5	28.8	15	31.0	28.2	43.7
14	21.9	22.0	26.5	16	29.1	26.7	40.2
15	20.5	20.5	24.0	17	27.3	25.4	37.4
16	19.1	19.5	22.0	18	25.7	24.3	34.8
17	17.9	18.5	21.5	19	24.3	23.2	32.4
18	16.8	17.6	21.0	20	23.0	22.2	30.1
19	15.7	17.0	20.5	21	21.8	21.3	28.4
20	14.5	16.5	20.0	22	20.8	20.5	26.8
Log run	26.0	23.1	32.9	23	19.9	19.8	25.7
				24	19.1	19.2	24.8
				25	18.4	18.6	23.9

SUGGESTIONS FOR COMPUTING CUTTING LIMITS

The following suggestions are set down for the use of the timber owner who wishes to compute for his own operation the results to be expected if he cuts his timber to certain diameter limits. Before attempting to make any computations it is suggested that the parts of this bulletin "How the work was done" and "Classification of costs," be reviewed carefully.

The first things an operator will need in working out his own cutting limits are volume distribution tables similar to Tables 3 and 4. He will also need to go into his own woods and cruise, say 15 sample acres located at different places on his holdings. From the cruiser's figures and volume tables he can then compute the volume distribution by species and diameter classes for his stand of timber. The values from these tables should then be applied to the figures for individual diameters which are given in this bulletin for the purpose of setting up production costs and lumber values for each diameter class that will apply to his own operation. An example will best illustrate the method:

Assume that the owner's volume distribution figures when multiplied by the total direct costs of logging for each diameter class, column 7, Table 8, give a weighted average of $8.80 instead of $8.38. Then suppose his average direct logging cost is $9.68. Subtracting $8.80 from $9.68 shows that his costs are 10 per cent higher than the figures used in this publication. Direct costs for each diameter class for his own operation can now be computed by simply increasing the costs given in this publication by 10 per cent. Logging 8-inch trees would then cost $19.10 a thousand board feet instead of $17.36; logging 20-inch trees, $8.19 instead of $7.45.

By this same procedure the owner can set up costs for individual diameters and weighted log-run figures for each step of logging. Overrun figures may be computed in a similar manner.

Milling costs can be calculated as in the preceding example, but in addition a weighted average cost within each diameter class should be computed because of the difference in the cost of sawing between hardwoods and softwoods. Likewise, the value of the lumber should be weighted within each diameter class as well as for the stand as a whole because of the difference in value of the various species.

With the above computations made the operator can compute the results when cutting to different diameter limits. The method of doing this has already been explained on page 30.

PREDICTION OF GROWTH IN STANDS SELECTIVELY CUT

Table 31, which is based on the actual relationships found by the study, shows what happens to the annual volume growth in stands from which merchantable timber has been removed by partial cutting in varying amounts from 42 to 99 per cent of the original stand, that is, from light cuttings to practically clear cuttings. If one of the factors named in the table is known or is easily determined in the field, one can predict all other factors affecting the growth of the stand. The most easily determined factor is the amount of merchantable volume left on a cut-over area, and the thing that any timber owner wishes most to know is what the remaining stand will produce during the next 20 to 30 years in the form of sawmill material. If, for instance, the timberland owner finds that after selective logging there is 3,000 board feet in the form of merchantable trees left, then, according to Table 31, the stand may be expected to grow at the rate of 5.5 per cent a year. By multiplying the growth per cent by the amount of merchantable timber left, the average annual growth per acre per year for the next 25 years is obtained:

$$\frac{5.5 \times 3000}{100} = 165 \text{ board feet.}$$

TABLE 31.—*Relation between amount of merchantable timber left, percentage of volume growth, and average annual growth in board feet*

Rough diameter cutting limit (inches)	Volume per acre left after cutting	Volume removed from original stand; basis, 13,000 board feet [1]	Volume growth per year in percentage of total volume left after cutting	Average gross annual increment per acre	Average period required to grow 1,000 board feet gross scale [1]	Character of cutting
	Board ft.[1]	*Per cent*	*Per cent*	*Board ft.*[1]	*Years*	
	13,000	----------	1.6	210	----------	Virgin stand.
20 or 22 and up	7,500	42	2.6	195	5	Light partial cutting.
	6,000	54	3.1	185	5½	
14 or 16 and up	3,300	75	5.2	170	6	Heavy partial cutting.
	2,400	82	6.6	160	6	
	1,900	86	8.1	155	6½	
	1,550	88	9.8	150	7	
12 or 13 and up	1,200	91	12.0	145	7	Very heavy partial cutting.
	900	93	15.0	135	7½	
	700	95	19.4	135	7½	
	450	97	24.6	110	9	
11 and up	210	98	31.0	65	15	Clear cutting.
	100	99	----------	45	22	

[1] Measured by Scribner Decimal C rule.

It must be borne in mind that the volume growth figures represent growth that took place in the course of about 25 years after the first cutting and refer to definite conditions at the time of cutting. In applying these figures to present cuttings the prediction must also extend only to a period of about 25 or 30 years in the future, as the conditions for which they hold true may change within that period. Much of the unmerchantable timber may become merchantable by that time and the entire rate of growth modified. The figures as given, therefore, are not yield values, but are merely a prediction of growth for definite conditions of cut-over areas, namely, a certain amount of merchantable timber left on the ground and a certain number of small unmerchantable trees in the stand.

Furthermore, the figures of growth are gross values. Deduction should be made for decay or natural mortality in the stand, which will vary according to the condition of the trees left, the injuries they received during the first logging, and the character of the soil in which they grow. Each timber owner will have to make his own estimate as to the amount that should be allowed for this loss. It will seldom, however, exceed 10 per cent of the annual increment.

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INHERITANCE OF COMPOSITION OF WASHINGTON NAVEL ORANGES OF VARIOUS STRAINS PROPAGATED AS BUD VARIANTS[1]

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CONTENTS

INTRODUCTION

The investigations described in this bulletin are similar to the studies on the composition of the bud variants of Eureka and Lisbon lemons, the report of which was published in Department of Agriculture Bulletin 1255, in 1924 (*3*).[2] The object of the investigations is discussed in that bulletin. Although the work reported here is similar to that done on lemons, there are a few differences that require explanation.

PLAN OF WORK

The preliminary work on both projects was carried out at the same time, but most of the work on the orange variants had to be postponed until after the report on lemons was published. Two periods of severely cold weather with subsequent poor crops delayed the project. Furthermore, the period of the year in which the Washington Navel orange is available for work is much shorter than that in which lemons can be obtained.

The buds from which the progeny lemon trees were grown were, with few exceptions, obtained from full-grown trees, so that little

[1] Assistance in the analytical work was received from F. E. Denny, H. D. Poore, and D. G. Sorber. Thanks are also due Doctor Denny for criticism of the manuscript.
[2] Italic numbers in parentheses refer to "Literature cited," p. 22.

difficulty was encountered in obtaining sufficient samples of fruit from the parent trees. Many of the buds from which the orange progeny trees were grown came from small limbs, which supplied far too few fruits for adequate samples for analyses, especially where considerable variation in composition was found. The data derived from the analysis of samples from parent trees are therefore somewhat meager, and the bulk of the comparisons are concerned with fruit from progeny trees. The sampling of the latter began as soon as the trees bore enough fruit to afford three sets of samples in one season.

In the Riverside district, where all the trees from which samples were obtained were located, commercial picking begins early in December, in order to reach the Christmas market, and lasts until April. It was planned therefore to obtain the first samples about December 1, the second set about January 15, and the final fruit early in March. This plan could not always be followed, but was adhered to as closely as possible.

When the possibility of undertaking the project was first broached in 1915, it was decided to collect a few preliminary samples in order to ascertain whether sufficient differences in composition could be found to justify further work. The preliminary samples were collected and analyzed in that season. Only a limited number of strains were chosen. The trees for sampling were selected by A. D. Shamel and C. S. Pomeroy, of the Bureau of Plant Industry, and included only the true Washington, Thomson, Yellow Thomson, Golden Nugget, Australian, and Yellow Washington strains. These trees were all growing in the foothill section of the Riverside district, and, where comparisons were made, the comparable trees were usually situated in close proximity in the same grove. The trees of each set were grown on the same type of soil and had been subjected to the same systems of fertilization, cultivation, and irrigation. In not a few cases comparable samples of different strains were obtained from the same tree, as it is not uncommon to find trees bearing several strains of fruit on different limbs, which have arisen as bud variations.

When the results of analyses of the preliminary samples seemed to indicate that sufficient differences in composition existed to warrant further investigation, the project was planned to include comparisons of samples from parent trees and from their progenies.

The parent trees, also, were selected by Shamel and Pomeroy. Most of them were growing in the same orchards from which the preliminary samples were secured, situated along the foothills of the Riverside district, so that climatically there was little difference in their environment. The samples from these trees were, as a whole, comparable, for although the trees were growing in different orchards under varying conditions of cultivation and fertilization, samples were collected in groups of two or more, fruit within the group coming either from the same tree or from trees growing in close proximity in the same grove. Thus individual samples of the Washington strain were not compared with those of a Thomson strain from another grove, but only with those grown in the same orchard.

The progeny trees were all growing in the grove of the Citrus Experiment Station of the University of California at Riverside; all were on soil of the same type and received identical cultivation and fertilization.

Comparisons of samples from trees in the progeny grove were made whenever possible between samples of fruit from trees of common parentage. When this could not be done they were made between fruit from trees located as near as possible to each other in the grove.

SAMPLING AND METHODS OF ANALYSIS

Samples consisted usually of 25 to 30 fruits, although smaller samples were sometimes taken in order to maintain the continuity of the data. In selecting fruits for the samples, preference was always given to fruits showing the physical characteristics of the strain being tested. A pomologist was always present and passed judgment on any doubtful fruits. At times 50 samples were collected at one picking, so that it was necessary to store some of the fruit for several days before it could be analyzed. When stored, the fruit was maintained at a temperature between 35° and 45° F., and care was taken to select the samples from storage in such a way as to prevent the delayed analyses from affecting the results on any one strain of fruit. Five fruits of each sample were used for oil determinations, which were made by the method of Wilson and Young (*11*). The specific gravity of the remaining fruit was determined by weighing it in air and under water. It was then dried and peeled by hand, as much as possible of the albedo being removed but not the segment walls. Both the peel and pulp were weighed, and the percentage of each was calculated, any loss falling where it had occurred.

The pulp was passed through a food grinder three times, and after being mixed a portion was removed for the determination of the insoluble solids. The juice was drained from the remainder, and the soluble solids were determined by means of a Brix spindle. Separate portions were then measured for determination of the total sugars and acid. The percentage of insoluble solids was ascertained by allowing the samples of pulp to soak in water containing some toluol for at least 24 hours and then washing them with cold water until the washings were free from acid. The samples were dried to constant weight at 100° C. in air.

Acid was determined at room temperature with phenolphthalein as indicator. The official method (*2, p. 192, No. 39*) was used for sugars, the cuprous oxide being dissolved in hot ferric sulphate and sulphuric acid and the resulting ferrous sulphate being titrated with permanganate solution.

METHOD OF MAKING COMPARISONS

In comparing the significance of the differences between strains of lemons as previously reported Peters' formula for calculating the probable errors was used (*5*). A better method for making comparisons existed, but could be employed in a limited number of cases only, owing to the fact that in the series being compared the individual fruits could not always be arranged in strictly comparable couples.

In planning the work on oranges the samples were collected in such a way that in each series the couples were strictly comparable. The data can therefore be compared by Student's method (*1, 4*). In Peters' method for probable errors, all variations are taken into account, as the method is based on the variation between the individuals in a series and the mean of the series. In Student's method, on the other hand, differences between the individual fruits composing each couple of the series are largely responsible for the results. Thus the first method takes into account variations due to differences in weather from year to year, differences due to the maturity of the fruit, to the location of the tree, etc., as well as the differences due to inheritance. The second method by making comparisons of two samples picked at the same time from two selected trees, eliminates most of the other differences and gives more weight to those due to inheritance. In other words, if a series extends over three years, samples being taken during five months each year, the first method would take into account not only differences between the first and third years' samples but between samples collected in November and those collected in April. The differences shown by Student's method would be largely based on differences between a series of couples, the individuals of each being picked on the same day. When the odds shown were less than 100 to 1, the difference was not taken to be more than possible. In many instances, however, the odds were found to be more then 10,000 to 1, and in such cases the differences were assumed to be highly significant.

For convenience in making comparisons, two strains, the true Washington and the Thomson, were used as types. It is true, of course, that all the strains being compared, including the Thomson, were variants of the Washington Navel, but comparison of each strain with every other strain would be cumbersome and voluminous. Therefore, those strains that approach the Washington in composition were compared with it, whereas those that are more nearly like the Thomson were compared with that strain. In only a few cases was it necessary to compare with both the Washington and the Thomson.

The comparisons naturally began with the true Washington and the Thomson strains, and in order to establish a ground work for subsequent use, the monthly averages of all Washington and Thomson samples from the progeny trees were obtained and are given in Table 1. These data were not strictly comparable but afforded an opportunity to study the monthly variation in samples of the two chief strains and to show that the differences which were brought out later exist throughout the year.

TABLE 1.—*Monthly averages on composition of all Washington and Thomson oranges from progeny trees*

Strain and month	Samples	Whole fruit			Pulp	Juice		
		Specific gravity	Peel	Oil	Insoluble solids	Soluble solids	Sugar	Acid
Washington:	*Number*		*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
November	8	0.892	31.5	0.542	2.74	11.40	7.92	1.22
December	10	.891	32.9	.574	2.92	12.45	8.59	1.25
January	4	.882	34.0	.548	2.52	13.23	9.67	1.16
February	13	.880	35.4	.549	2.50	13.72	10.06	.98
March	8	.908	34.5	.539	2.46	14.15	10.06	.88
Thomson:								
November	11	.885	31.8	.319	2.98	11.57	8.45	.99
December	18	.886	32.9	.349	3.19	12.60	9.04	1.13
January	6	.879	36.0	.291	3.03	13.62	10.19	1.01
February	20	.881	35.1	.273	2.80	14.34	10.68	.87
March	12	.910	34.6	.280	2.58	14.73	10.19	.76

COMPARISON OF THE WASHINGTON AND THE THOMSON STRAINS

Next to the true Washington strain, the Thomson is the most important of the 13 or more strains identified by Shamel, Scott, and Pomeroy (*10*). Owing to its early maturity and smooth skin, it has established a place in the industry, and there are a substantial number of groves of this strain in California, but at present it is being propagated to only a small extent. It has also been known as Thomson's Improved and Washington Improved. The fruits are similar in size and shape to the Washington, but they are of a more reddish-orange color, and the skin is smoother, with fewer oil cells apparent on its surface. The texture of the pulp is coarse, and this strain is known to the trade as a "woody" orange. The juice is less acid, and, perhaps partly for this reason, it is often thought to be sweeter than the Washington.

The data upon which comparisons were based (Table 2) reveal that many of the physical differences mentioned above are correlated with the chemical composition.

TABLE 2.—*Comparison of the composition of the Washington and the Thomson strains*

PRELIMINARY SAMPLES

Date	Whole fruit						Pulp		Juice							
	Specific gravity		Peel		Oil [1]		Insoluble solids		Soluble solids		Sugar		Acid		Ratio soluble solids—acid	
	Washington	Thomson	Washington	Thomson	Washington	Thomson	Washington	Thomson	Washington	Thomson	Washington	Thomson	Washington	Thomson	Washington	Thomson
			P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct*	*P. ct.*		
Mar. 31, 1915	0.882	0.867	27.1	27.9	0.358	0.085	1.77	2.34	12.85	14.00	8.96	10.17	0.61	.51	21.1	27.5
Apr. 1, 1915	.909	.912	27.5	23.9	.357	.143	2.05	2.46	13.73	14.49	9.51	10.15	.65	.56	21.1	25.9
Jan. 8, 1916	.921	.911	23.4	24.1	.42	.15	2.15	2.88	12.51	13.33	9.61	10.00	1.08	.95	11.6	14.0
Feb. 8, 1916	.911	.904	24.3	24.5	.32	.21	2.01	2.89	12.88	13.10	9.81	10.17	.90	.79	14.3	16.6
Mar. 8, 1916	.934	.911	23.7	22.9	.39	.16	2.22	2.78	13.85	14.49	10.93	11.44	.86	.70	16.1	20.7
Average	.911	.901	25.2	24.7	.37	.15	2.04	2.67	13.16	13.88	9.76	10.39	.82	.70	16.8	20.9
SAMPLES FROM PARENT TREES																
Dec. 5, 1922	0.918	0.871	31.3	34.4	-----	-----	3.68	3.96	13.79	13.23	9.17	11.05	1.29	1.05	10.7	12.6
Do	.897	.914	35.6	29.9	-----	-----	3.68	3.96	14.30	14.70	9.17	11.05	1.18	1.04	12.1	14.1
Jan. 9, 1923	.888	.878	34.7	32.2	0.643	0.288	3.27	3.46	14.81	14.43	11.33	11.20	1.02	.84	14.5	17.2
Feb. 20, 1923	.888	.862	35.6	36.9	.613	.254	3.08	3.25	15.84	15.27	12.09	11.78	.96	.73	16.5	20.9
Feb. 14, 1924	.921	.916	31.4	30.9	.930	.338	3.14	3.54	15.44	15.28	11.58	11.80	.85	.74	18.2	20.6
Do	.913	.915	28.4	27.8	.550	.360	2.72	3.19	14.20	15.51	11.67	12.06	.90	.70	15.8	22.2
Dec. 1, 1924	.931	.930	29.0	28.2	.909	.529	3.20	3.72	12.78	13.02	9.07	9.41	1.04	.86	12.3	15.1
Do	.925	.932	27.8	25.1	.698	.423	2.78	3.32	13.23	13.90	9.72	10.24	1.06	.82	12.5	17.0
Nov. 30, 1925	.918	.912	25.8	25.1	.550	.254	2.76	3.19	12.03	13.13	9.43	10.22	.88	.72	13.7	18.2
Average	.911	.903	31.1	30.1	.699	.349	3.15	3.51	14.05	14.27	10.36	10.98	1.02	.83	14.0	17.5

[1] The low results on the preliminary samples are possibly owing to the imperfect method used at that time. They are included because they are comparable.

TABLE 2.—*Comparison of the composition of the Washington and the Thomson strains*—Continued

SAMPLES FROM PROGENY TREES

Date	Whole fruit						Pulp		Juice							
	Specific gravity		Peel		Oil		Insoluble solids		Soluble solids		Sugar		Acid		Ratio soluble solids—acid	
	Washington	Thomson	Washington	Thomson	Washington	Thomson	Washington	Thomson	Washington	Thomson	Washington	Thomson	Washington	Thomson	Washington	Thomson
			P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*		
Dec. 5, 1922	0.893	0.870	30.7	33.5	-----	-----	3.30	3.08	12.04	11.21	8.39	8.18	1.38	0.95	8.7	11.8
Feb. 19, 1923	.854	.877	37.4	36.3	0.656	0.381	2.67	2.76	13.74	14.16	10.09	10.61	.98	.88	14.1	16.1
Feb. 14, 1924	.893	.908	32.9	29.4	.592	.212	2.61	2.65	13.26	13.86	9.72	10.32	1.02	.77	13.0	18.0
Dec. 1, 1924	.892	.907	33.5	30.4	.571	.317	2.88	2.91	12.42	13.01	8.55	9.41	1.20	1.06	10.4	12.3
Nov. 30, 1925	.891	.900	31.8	28.7	.571	.296	2.90	2.95	11.72	11.73	8.19	8.77	1.28	.95	9.2	12.3
Mar. 2, 1926	.906	.912	34.2	33.3	.529	.338	2.64	2.45	14.43	14.98	10.31	10.67	.90	.75	16.0	20.0
Dec. 5, 1922	.876	.868	36.4	33.7	-----	-----	3.26	3.68	11.51	11.76	7.96	9.35	1.12	1.10	10.3	10.2
Feb. 19, 1923	.868	.849	39.7	38.6	.634	.338	2.48	2.96	13.71	14.66	10.22	11.20	.87	.87	15.8	16.8
Feb. 14, 1924	.893	.889	31.5	34.0	.508	.275	2.45	2.84	12.63	14.33	9.50	10.72	.88	.82	14.4	17.6
Dec. 1, 1924	.911	.890	31.4	33.6	.719	.392	2.85	3.02	12.59	12.63	8.68	8.90	1.11	1.02	11.3	12.4
Nov. 30, 1925	.894	.880	31.5	34.3	.635	.317	2.73	3.11	10.88	11.88	7.88	8.56	1.11	.94	9.8	12.8
Mar. 2, 1925	.907	.913	36.8	36.2	.634	.275	2.45	2.58	13.85	15.11	10.05	11.13	.78	.72	17.8	21.2
Feb. 19, 1923	.873	.864	37.8	39.1	.613	.254	2.62	2.72	13.93	15.68	10.00	10.92	1.05	1.01	13.3	15.5
Feb. 14, 1924	.909	.898	33.6	33.6	.592	.296	2.52	3.10	14.12	14.26	10.11	10.28	1.10	.90	12.8	15.8
Dec. 1, 1924	.899	.900	32.1	32.2	.677	.360	2.72	3.12	12.30	12.40	8.46	8.50	1.22	1.10	10.1	11.3
Nov. 30, 1925	.903	.893	33.4	30.6	.550	.275	2.79	2.98	11.58	11.48	8.11	8.45	1.27	1.08	9.1	10.6
Mar. 2, 1925	.913	.912	37.3	35.8	.592	.296	2.47	2.78	14.47	15.04	10.12	10.88	.97	.77	14.9	19.5
Dec. 5, 1922	.863	.861	35.6	34.1	-----	-----	3.00	3.56	11.64	11.81	7.83	8.96	1.23	1.08	9.5	10.9
Feb. 19, 1923	.861	.856	37.1	39.0	-----	-----	2.62	2.72	13.38	13.88	10.00	10.92	.94	.85	14.2	16.3
Feb. 14, 1924	.904	.891	31.0	32.6	-----	-----	2.52	3.10	13.55	13.53	10.11	10.28	1.08	.90	12.5	15.0
Dec. 1, 1924	.912	.911	30.4	30.1	.508	.317	2.80	2.59	12.29	11.91	8.29	8.20	1.26	.98	9.8	12.2
Nov. 30, 1925	.891	.885	31.6	31.0	.550	.275	2.79	2.98	11.18	11.33	7.95	8.20	1.31	.98	8.5	11.6
Mar. 2, 1926	.914	.904	34.4	34.2	.592	.296	2.47	2.78	14.03	14.97	9.78	9.90	.94	.74	14.9	20.2
Average	.892	.889	34.0	33.7	.596	.306	2.72	2.93	12.84	13.29	9.14	9.71	1.09	.92	12.2	14.8

The 10 comparable preliminary samples showed sufficient evidence of marked differences to warrant proceeding further with the investigation. The oil content of the fruit, the insoluble solids of the pulp, and the acid of the juice were consistently different in amount from those of the true Washington strain. The odds that two of these differences are significant are not far from 1,000 to 1, but the odds pertaining to the difference in acidity of the juice are more than 10,000 to 1. There was some indication also that differences between the two strains in specific gravity of the fruit and sugar content of the juice might exist.

From 6 to 10 years later another series of samples was collected consisting of 9 from parent trees and 23 from their progenies. The data from these samples exhibit the characteristic differences found in the preliminary samples. The Thomson-strain fruit again contained only about half the oil found in the Washington strain; it had more insoluble solids in the pulp and less acid in the juice. Again the odds are more than 10,000 to 1 that the differences are significant except in the case of the insoluble solids of the progeny samples, the odds here falling to about 1,600 to 1, owing to the three reversals of the tendency in the 23 samples. The data do not show a marked difference in the specific gravity of the fruit or in the content of soluble solids in the juice.

The data on the percentage of sugar in the juice present something of an anomaly. The samples from the parent trees showed a higher sugar content in the juice of the Thomson fruit, but in 2 instances out of 9 the reverse was true. The odds are 4 to 1 that the difference is significant. The progeny-tree samples had only 2 cases out of 23 where the Washington strain was higher in sugar. The odds are more than 10,000 to 1 in this case that the difference exists. It must be remembered that differences in composition ought to be more manifest in the progeny samples. The trees were of the same age and were receiving identical treatment, which was not the case with the parent-tree samples. The trees from which the parent and preliminary samples were taken were under different systems of management. Each of the two samples of a set were comparable, but the sets of samples varied more widely than did those of the progeny trees. Naturally the odds are not so great that the differences are significant.

There seems to be little room for doubt that some differences between these strains are significant and that in practically all cases where samples are comparable these differences will be found. The oil content of the Thomson fruit was only about one-half that usually found in fruit of the Washington strain. This is apparent on close observation. Fruit of the two types growing on the same tree showed this difference, and it was even more striking in samples from progeny trees. None of the samples from any of the trees showed a reversal of this tendency. The acidity of the juice of fruits of these two strains almost always showed a small but consistent difference, the true Washington strain containing more acid than the Thomson. Inasmuch as the soluble solids in the juice were nearly the same, the soluble solids-acid ratio of the juice of Thomson oranges was almost always higher than that of the other strain.

The pulp of the Thomson fruit is coarser and more woody than that of the Washington, the insoluble solids being higher. Very few reversals of this tendency occurred in the samples, only 3 of the 32 showing it. Although the juice of the Thomson strain had a higher sugar content than that of the Washington strain, this difference was less convincing than the difference in insoluble solids. All the preliminary samples, as well as 7 of the 9 samples from parent trees and 21 of the 23 samples from progeny trees, showed the tendency. Only 10.8 per cent of the samples showed a reversal of the tendency. Other differences were not found to be significant.

The data on these samples agree very closely with those in Table 1, where the general averages for all samples of the Washington and the Thomson strains are summarized.

AUSTRALIAN STRAIN

In appearance the fruit of the so-called Australian strain closely resembles that of the true Washington strain (*6*). The trees at one time were abundantly scattered throughout the groves in both southern and central California and were normally quite unproductive. They were never intentionally propagated, and their presence was probably owing to the fact that their abundant foliage offered excellent opportunity for easily secured budding material. The fruit is described as yellowish orange in color, the rag is abundant and coarse, and the juice is small in quantity and of inferior quality.[3] The strain is late in maturing, and for this reason many of the trees are being budded over in regions where the true strains mature early.

Inasmuch as there were but two preliminary samples and none from parent trees, all the samples can be considered at the same time.

The data show that the composition of the Australian strain differs distinctly from that of the true Washington with respect to each of the items determined, with two exceptions, namely, specific gravity of the whole fruit and percentage of peel. (Table 3.) The Australian strain contains more oil, and its juice has more acid. It has less insoluble matter in the pulp and less soluble solids and sugars in the juice. The latter fact in conjunction with the higher acidity gives its juice a lower soluble solids-acid ratio. The odds that these differences are significant are all more than 10,000 to 1, whereas they are but 47 and 68 to 1, respectively, that the differences in specific gravity and percentage of peel are significant.

Table 3.—*Comparison of the composition of the Washington and the Australian strains*

Date	Whole fruit						Pulp		Juice							
	Specific gravity		Peel		Oil		Insoluble solids		Soluble solids		Sugar		Acid		Ratio soluble solids-acid	
	Washington	Australian	Washington	Australian	Washington	Australian	Washington	Australian	Washington	Australian	Washington	Australian	Washington	Australian	Washington	Australian
			P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*		
Feb. 19, 1923	0.873	0.857	37.8	38.7	0.613	0.740	2.62	2.23	13.93	11.77	10.00	8.65	1.05	1.03	13.3	11.4
Do	.861	.865	37.1	38.7	-----	-----	2.62	2.23	13.38	12.27	10.00	8.65	.94	1.18	14.2	10.4
Do	.850	.884	36.6	34.4	.656	.846	2.67	2.25	13.22	12.84	10.09	8.87	.94	1.21	14.1	10.6
Do	.858	.849	38.2	41.4	-----	-----	2.67	2.25	14.26	12.84	10.09	8.87	1.01	1.16	14.1	11.1
Feb. 21, 1924	.909	.919	33.6	29.1	.592	.846	2.52	2.33	14.12	12.63	10.11	8.98	1.10	1.16	12.8	10.9
Do	.904	.916	31.0	29.8	-----	-----	2.52	2.33	13.55	12.85	10.11	8.98	1.08	1.35	12.5	9.5
Do	.888	.898	34.2	32.8	.592	.930	2.61	2.18	13.18	12.90	9.72	8.98	1.08	1.35	12.2	9.6
Do	.898	.916	31.6	29.9	-----	-----	2.61	2.18	13.34	12.85	9.72	8.98	.97	1.19	13.7	10.8
Nov. 30, 1925	.903	.911	33.4	29.8	.550	.656	2.79	2.46	11.58	10.88	8.11	7.63	1.27	1.31	9.1	8.3
Do	.891	.918	31.6	28.5	.550	.656	2.79	2.46	11.18	10.95	7.95	7.29	1.31	1.53	8.5	7.2
Do	.880	.905	33.4	30.4	.571	.698	2.90	2.58	11.48	11.55	8.03	8.11	1.26	1.63	9.1	7.1
Do	.902	.913	30.2	29.8	.571	.698	2.90	2.58	11.96	11.02	8.35	7.46	1.29	1.52	9.3	7.3
Mar. 2, 1926	.913	.906	37.3	34.3	.592	.613	2.47	2.25	14.47	12.05	10.12	8.19	.97	1.08	14.9	11.2
Do	.914	.920	34.4	32.4	.592	.613	2.47	2.25	14.03	12.63	9.78	8.79	.94	1.07	14.9	11.8
Do	.900	.910	34.8	32.8	.529	.719	2.64	2.21	14.37	12.19	10.03	8.65	.89	1.12	16.1	10.9
Do	.912	.901	33.5	34.9	.529	.719	2.64	2.21	14.50	12.59	10.59	8.74	.91	1.03	15.9	12.2
Average	.891	.899	34.3	33.0	.578	.728	2.65	2.31	13.28	12.17	9.55	8.49	1.06	1.24	12.8	10.0

YELLOW WASHINGTON STRAIN

In size, shape, character of peel, number of oil cells apparent, and texture and taste of pulp, the fruits of the Yellow Washington strain differ but little from those of the true Washington. The color, however, is light yellow, shading to orange yellow late in the season. A few groves of this fruit exist, but as the market usually discriminates against the light color the fruit is not popular.

[3] Descriptions of fruit in the text are taken from publications of A. D. Shamel, C. S. Pomeroy, and R. E. Caryl.

Eight preliminary samples and eight from the experiment station grove were collected. The data (Table 4) do not reveal marked differences in composition except perhaps in specific gravity, which was higher in the Yellow Washington strain, and if the two groups (preliminary and progeny) are considered as one, the odds are more than 660 to 1 that this difference is significant. There were, however, four reversals of the tendency in the 16 samples.

TABLE 4.—*Comparison of the composition of the Washington and the Yellow Washington strains*

PRELIMINARY SAMPLES

Date	Whole fruit						Pulp		Juice					
	Specific gravity		Peel		Oil		Insoluble solids		Soluble solids		Sugar		Acid	
	Washington	Yellow Washington	Washington	Yellow Washington	Washington	Yellow Washington	Washington	Yellow Washington	Washington	Yellow Washington	Washington	Yellow Washington	Washington	Yellow Washington
			P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
May 8, 1915	0.915	0.913	25.9	27.2	------	------	1.71	1.71	16.11	14.64	11.41	10.56	0.73	0.60
Jan. 10, 1916	.904	.936	25.8	23.4	0.36	0.46	2.99	3.34	13.57	13.26	10.44	10.41	1.04	.86
Do	.913	.913	24.1	27.3	.45	.42	2.50	2.40	13.09	13.97	10.13	10.63	.91	.95
Feb. 9, 1916	.880	.930	26.7	25.5	.44	.59	2.36	2.32	13.46	13.47	10.59	10.91	.84	.82
Do	.899	.920	27.1	26.2	.51	.47	2.91	2.02	13.03	14.26	10.36	10.79	.81	.88
Mar. 9, 1916	.922	.941	27.2	25.0	.46	.52	2.17	2.53	14.97	14.87	11.40	11.68	.77	.79
Do	.921	.932	27.2	26.1	.51	.49	1.99	2.29	14.52	15.23	11.31	11.87	.70	.78
Apr. 2, 1916	.925	.935	28.2	26.1	.43	.52	1.97	2.46	15.57	15.84	11.57	12.21	.69	.58
Average	.910	.928	26.5	25.8	.45	.50	2.32	2.38	14.29	14.44	10.90	11.13	.81	.78
SAMPLES FROM PROGENY TREES														
Nov. 30, 1925	0.895	0.893	29.6	32.7	0.465	0.508	2.53	2.90	11.23	11.69	7.45	8.36	1.18	1.10
Mar. 2, 1926	.912	.916	31.8	34.1	.486	.550	2.29	2.50	13.70	14.17	9.79	9.60	.86	.92
Nov. 30, 1925	.882	.894	32.6	32.0	.465	.508	2.53	2.90	11.22	11.76	7.87	8.36	1.19	1.18
Mar. 2, 1926	.905	.927	34.0	32.7	.486	.550	2.29	2.50	14.00	14.72	9.88	10.11	.91	.89
Nov. 30, 1925	.880	.895	33.4	31.4	.571	.529	2.90	2.79	11.48	11.59	8.03	8.28	1.26	1.15
Mar. 2, 1926	.900	.914	34.8	34.5	.529	.613	2.64	2.46	14.37	14.44	10.03	8.82	.89	.87
Nov. 30, 1925	.902	.892	30.2	30.7	.571	.529	2.90	2.79	11.96	11.23	8.35	7.87	1.29	1.17
Mar. 2 1926	.912	.920	33.5	33.6	.529	.613	2.64	2.46	14.50	14.09	10.59	10.01	.91	.88
Average	.898	.906	32.5	32.7	.513	.550	2.59	2.66	12.81	12.96	9.00	8.93	1.06	1.02

SEAMED WASHINGTON STRAIN

The Seamed Washington strain is of no commercial value, but it affords a striking example of the inheritance of composition. The fruits have sharply defined furrows or seams in the peel and are rather deeply pitted. They are somewhat lighter yellow than those of the comparable Washington samples.

Samples were obtained from two trees in the experiment station grove, both propagated from the same parent tree, and comparisons were made with samples from two Washington-strain trees also propagated from this parent tree. All these progeny trees were growing in close proximity in the row. Five samples from each of the trees were collected, making 10 of each strain available for comparison.

The fruit of this strain has about one and one-third times more peel than the average Washington Navel fruit and is therefore lower in specific gravity. The fruit is coarse in texture, having more insoluble solids in its pulp. The odds that these differences are significant are more than 10,000 to 1. The juice of this fruit was somewhat more acid than that of the Washington strain, the odds being 3,000 to 1 that the small difference shown is significant. A rather unusual variation in the oil content of this fruit was found. The samples from the two progeny trees collected early in March, 1926, had but 0.23 per cent oil, whereas those collected late in February the following year had about twice that quantity. A like variation was not exhibited by the companion trees of the Washington strain, which in every instance except one contained more oil, the odds being about 60 to 1 that the difference is significant. In Table 5 is shown the comparison of the Seamed Washington strain and the Washington strain.

TABLE 5.—*Comparison of the composition of the Washington and the Seamed Washington strains*

Date	Whole fruit						Pulp		Juice					
	Specific gravity		Peel		Oil		Insoluble solids		Soluble solids		Sugar		Acid	
	Washington	Seamed Washington	Washington	Seamed Washington	Washington	Seamed Washington	Washington	Seamed Washington	Washington	Seamed Washington	Washington	Seamed Washington	Washington	Seamed Washington
			P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Nov. 30, 1925	0.895	0.873	29.6	39.6	0.465	0.444	2.53	3.02	11.23	10.93	7.45	7.80	1.18	1.37
Mar. 2, 1926	.912	.870	31.8	45.0	.486	.233	2.29	2.84	13.70	14.84	9.79	10.52	.86	1.05
Dec. 7, 1926	.886	.868	30.9	42.3	.465	.423	2.62	3.19	13.36	13.69	9.34	9.64	1.38	1.44
Jan. 10, 1927	.889	.860	32.6	44.2	.455	.391	2.08	2.77	13.46	13.33	9.81	9.60	1.21	1.30
Feb. 24, 1927	.878	.847	36.0	47.8	.423	.453	2.23	2.34	14.06	14.99	9.99	10.26	.99	1.22
Nov. 30, 1925	.882	.870	32.6	39.0	.465	.444	2.53	3.02	11.22	11.27	7.87	7.87	1.19	1.36
Mar. 2, 1926	.905	.879	34.0	42.9	.486	.233	2.29	2.84	14.00	14.87	9.88	10.88	.91	.93
Dec. 7, 1926	.882	.856	34.8	41.6	.529	.465	2.88	3.10	13.89	13.16	9.89	9.30	1.41	1.59
Jan. 10, 1927	.899	.841	33.6	46.8	.550	.391	2.56	2.73	14.39	14.20	10.39	9.93	1.27	1.28
Feb. 24, 1927	.882	.829	38.8	48.2	.457	.423	2.35	2.54	15.29	15.99	11.03	9.65	1.08	1.21
Average	.891	.859	33.5	43.7	.478	.390	2.44	2.84	13.46	13.73	9.54	9.51	1.15	1.27

DRY STRAIN

The Dry strain (*10*) is a worthless sport, but occurs as a limb mutation on trees bearing normal fruits. These oranges are globular or oblong, from small to medium size, and the rinds are very thick and coarse. The fruits are yellowish orange in color, seedless, and have medium to large navels. A cross section of the fruit shows them to be composed of white rag with a small section of pulp at the center. Two types of this strain have been designated as the "solid" and "hollow" forms. Only the former has been studied in this investigation.

The six samples collected were compared with a like number from a Washington-strain tree growing near by but not of common parentage. (Table 6.) The Washington-strain samples did not show any great difference from the general averages for the Washington strain, but had slightly more oil and somewhat less soluble solids, sugar, and acid.

TABLE 6.—*Comparison of the composition of the Washington and the Dry strains*

Date	Whole fruit						Pulp		Juice					
	Specific gravity		Peel		Oil		Insoluble solids		Soluble solids		Sugar		Acid	
	Washington	Dry	Washington	Dry	Washington	Dry	Washington	Dry	Washington	Dry	Washington	Dry	Washington	Dry
			P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Dec. 5, 1922	0.876	0.796	36.4	50.9	------	------	3.26	7.53	------	------	7.96	8.65	1.12	1.00
Feb. 19, 1923	.868	.772	39.7	54.2	0.634	0.656	2.48	5.55	13.71	13.43	10.22	10.39	.87	.76
Feb. 14, 1924	.893	.819	31.5	44.6	.508	.634	2.45	5.80	12.63	12.16	9.50	10.41	.88	.78
Dec. 1, 1924	.911	.825	31.4	48.4	.719	.592	2.85	5.83	12.59	10.58	8.68	7.77	1.11	.88
Nov. 30, 1925	.894	.791	31.5	51.8	.635	.571	2.73	8.10	10.88	11.59	7.88	7.81	1.11	.77
Mar. 2, 1926	.907	.836	36.8	55.0	.634	.465	2.45	5.78	13.85	14.78	10.05	10.94	.78	.69
Average	.892	.806	34.6	50.8	.626	.585	2.70	6.43	12.73	12.51	9.05	9.33	.98	.81

The fruit of the Dry strain is also characterized by a high percentage of peel and the correlated low specific gravity of the fruit. It averaged one and one-half times more peel than the fruit from the neighboring Washington tree and had an average specific gravity of only a little more than 0.800. The insoluble solids of the pulp were unusually high. The odds are 10,000 to 1 that the first two differences are significant and 5,000 to 1 that the third one is. The juices of the two strains did not differ greatly except in acid content, the Dry strain being consistently lower, with odds of 200 to 1 that the existing difference is significant.

BROWN SPOTTED STRAIN

The parent tree of the Brown Spotted strain was of the Thomson strain, but it had a limb bearing fruits of the Washington strain with coarse protruding navels, another limb bearing normal Washington fruits, and another bearing the small early-ripening fruits of the Brown Spotted strain. The fruits of the Brown Spotted strain were flattened in shape, pale yellow in color with occasional reddish stripes, and had irregular sunken brown spots. The rinds were thick, and the flesh was coarse and tough. As the fruit drops early in the season some difficulty was experienced in obtaining samples, none being secured from the parent limb after January or from the progeny trees after February. No samples were taken of the fruits with the protruding navels as there was some doubt whether this characteristic was transmitted to the progeny, but the other strains were studied. Not only was an excellent opportunity afforded to compare three strains all propagated originally from the same bud, but also to compare progeny grown from buds taken from the parts of the tree bearing the variants.

The Washington and Thomson fruits differed slightly in composition from those used in getting the general averages shown in Table 1. This was in part owing to the fact that in order to make the data comparable with those derived from analysis of the Brown Spotted fruit, only samples collected at the same time were used.

It will be noted that the Thomson-strain fruit from these trees differed in the usual way from the fruit of the Washington strain, being lower in oil content, higher in insoluble solids of the pulp, higher in sugar content, and lower in acid.

The Brown Spotted strain was lower in specific gravity than either of the others and had much more peel and insoluble solids. The odds are 10,000 to 1 that the differences shown in both peel and insoluble solids are significant and 3,000 to 1 that the difference in specific gravity between this fruit and the Washington is significant. The Brown Spotted strain has less oil than either the Thomson or Washington. In part this is caused by the fact that the brown spots or areas on the skin have apparently lost their oil cells. These spots are not unlike the injury caused by slight bruising and resulting damage to the skin by oil from the ruptured cells. The odds are 10,000 and 1,400 to 1, respectively, that the difference in oil content between this strain and the Washington and Thomson is significant. The juice of the strain is not characteristic. Table 7 gives the comparison of the Washington and Brown Spotted strains, and of the Thomson and Brown Spotted strains.

TABLE 7.—*Comparison of the composition of the Brown Spotted strain with that of the Washington and the Thomson strains*

Date	Whole fruit									Pulp		
	Specific gravity			Peel			Oil			Insoluble solids		
	Washington	Brown Spotted	Thomson	Washington	Brown Spotted	Thomson	Washington	Brown Spotted	Thomson	Washington	Brown Spotted	Thomson
				Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
Dec. 5, 1922	0.918	0.886	0.871	31.3	46.8	34.4	0.571	0.212		3.68	4.91	3.96
Dec. 5, 1922	.863	.855	.861	35.6	48.0	34.1				3.00	4.53	3.56
Jan. 9, 1923	.888	.883		34.7	45.5		.643	.212		3.27	4.47	
Jan. 9, 1923	.890	.858		34.1	54.0		.656	.275		2.87	3.52	
Feb. 19, 1923	.861	.839	.856	37.1	56.8	39.0				2.62	4.61	2.72
Feb. 14, 1924	.909	.894	.898	33.6	49.0	33.6	.592	.254	0.296	2.52	3.73	3.10
Feb. 14, 1924	.904	.888	.891	31.0	49.2	32.6				2.52	3.73	3.10
Dec. 1, 1924	.931	.910	.930	29.0	44.1	28.2	.909	.423	.529	3.20	4.50	3.72
Dec. 1, 1924	.899	.905	.900	32.1	46.4	32.2	.677	.233	.360	2.72	3.42	3.12
Dec. 1, 1924	.912	.906	.911	30.4	48.9	30.1	.508	.233	.317	2.80	3.78	2.59
Nov. 30, 1925	.903	.875	.893	33.4	51.1	30.6	.550	.212	.275	2.79	3.92	2.98
Nov. 30, 1925	.891	.865	.885	31.6	50.4	31.0	.550	.212	.275	2.79	3.92	2.98
Average	.897	.880	.890	32.8	49.2	32.6	.628	.252	.342	2.90	4.09	3.18
		[1] .882			[1] 49.1			[1] .261			[1] 4.10	

Date	Juice								
	Soluble solids			Sugar			Acid		
	Washington	Brown Spotted	Thomson	Washington	Brown Spotted	Thomson	Washington	Brown Spotted	Thomson
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Dec. 5, 1922	13.79	13.43	13.23	9.17	7.13	11.05	1.29	1.07	1.05
Dec. 5, 1922	11.64	12.12	11.81	7.83	8.61	8.96	1.23	1.22	1.08
Jan. 9, 1923				11.33	10.26		1.02	.90	
Jan. 9, 1923	12.93	13.31		9.44	9.30		1.14	.92	
Feb. 19, 1923	13.38	17.09	13.88	10.00	11.87	10.92	.94	1.16	.85
Feb. 14, 1924	14.12	14.55	14.26	10.11	10.80	10.28	1.10	1.06	.90
Feb. 14, 1924	13.55	14.37	13.53	10.11	10.80	10.28	1.08	1.12	.90
Dec. 1, 1924	12.78	12.60	13.02	9.07	8.37	9.41	1.04	1.00	.86
Dec. 1, 1924	12.30	11.82	12.40	8.46	7.59	8.50	1.22	1.02	1.10
Dec. 1, 1924	12.29	12.53	11.91	8.29	8.20	8.20	1.26	1.18	.98
Nov. 30, 1925	11.58	10.19	11.48	8.11	6.98	8.45	1.27	1.07	1.08
Nov. 30, 1925	11.18	9.49	11.33	7.95	7.17	8.20	1.31	1.11	.98
Average	12.68	12.86	12.68	9.16	8.92	9.43	1.16	1.07	.98
		[1] 12.82			[1] 8.75			[1] 1.10	

[1] Average of Brown Spotted samples comparable with Thomson samples.

CORRUGATED STRAIN

The fruits of the Corrugated strain are very different from those of the other Washington Navel orange strains, in that they are prominently ridged or corrugated (*10*). As a rule they are globose in shape and of large size. The rind is of medium thickness, and the color is deep orange. The rag is tender and small in quantity, and the juice is abundant and of good quality. The fruits are seedless, and the navels are small to medium. Fruits of this strain occur as individual fruit or limb variations in trees of both the Washington and Thomson strains. On account of the peculiar and prominent marking of the fruits, this strain is one of the most interesting and important of those resulting from the bud variations of the Washington Navel orange.

All the samples used in making comparisons between this strain and the Thomson and Washington were from trees of common parentage. The fruit is characterized by low specific gravity and high percentage of peel. (Table 8.) The oil and insoluble-solids content of the pulp are like those of the Thomson, but the sugar and acid content of the juice are more nearly like those of the Washington. The specific gravity of the fruit varied to such an extent that the differences shown between the strains are somewhat doubtful, the odds being 50 and 127 to 1 that this fruit is lower respectively than the Washington and Thomson strains. The average proportion of peel was higher than that of either of the other strains, odds of 10,000 and 1,400 to 1 prevailing that these differences between it and the Washington and Thomson respectively are significant. There was a significant difference between the oil content of this strain and that of the Washington, but no appreciable difference existed between it and the oil content of the Thomson. The insoluble solids in the pulp were also somewhat greater than in the Washington, the odds being about 200 to 1 that this difference is significant. The chances are 10,000 to 1 that the juice of this fruit is more acid than the Thomson. Other differences were not significant.

TABLE 8.—*Comparison of the composition of the Corrugated strain with that of the Thomson and the Washington strains*

THOMSON AND CORRUGATED STRAINS

Date	Whole fruit						Pulp		Juice					
	Specific gravity		Peel		Oil		Insoluble solids		Soluble solids		Sugar		Acid	
	Thomson	Corrugated	Thomson	Corrugated	Thomson	Corrugated	Thomson	Corrugated	Thomson	Corrugated	Thomson	Corrugated	Thomson	Corrugated
			P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Dec. 5, 1922	0.870	0.869	33.5	37.7	------	------	3.08	3.08	11.21	11.35	8.18	7.74	0.95	1.22
Feb. 19, 1923	.877	.866	36.3	43.8	0.381	0.296	2.76	3.10	14.16	14.56	10.61	10.57	.88	1.06
Feb. 14, 1924	.908	.874	29.4	34.3	.212	.338	2.65	3.21	13.86	14.06	10.32	10.11	.77	1.14
Dec. 1, 1924	.907	.867	30.4	42.5	.317	.338	2.91	3.42	13.01	12.22	9.41	7.90	1.06	1.22
Nov. 30, 1925	.900	.845	28.7	38.0	.296	.423	2.95	3.02	11.73	10.52	8.77	7.14	.95	1.20
Mar. 2, 1926	.912	.877	33.3	44.2	.338	.423	2.45	2.58	14.98	13.54	10.67	9.38	.75	.92
Average	.896	.866	31.9	40.1	.309	.364	2.80	3.07	13.16	12.71	9.66	8.81	.89	1.13

TABLE 8.—*Comparison of the composition of the Corrugated strain with that of the Thomson and the Washington strains*—Continued

WASHINGTON AND CORRUGATED STRAINS

Date	Whole fruit						Pulp		Juice					
	Specific gravity		Peel		Oil		Insoluble solids		Soluble solids		Sugar		Acid	
	Washington	Corrugated	Washington	Corrugated	Washington	Corrugated	Washington	Corrugated	Washington	Corrugated	Washington	Corrugated	Washington	Corrugated
Jan. 9, 1923	0.851	0.854	35.9	45.6	0.529	0.508	2.55	2.93	12.13	12.85	9.04	9.52	1.00	1.18
Feb. 19, 1923	.850	.872	36.6	45.8	.656	.296	2.67	3.10	13.22	15.06	10.09	10.57	.94	1.10
Feb. 14, 1924	.888	.869	34.2	41.0	.592	.338	2.61	3.21	13.18	14.00	9.72	10.11	1.08	1.16
Dec. 1, 1924	.895	.864	32.9	46.9	.550	.402	2.97	3.69	12.41	12.58	8.55	8.11	1.15	1.24
Mar. 2, 1926	.900	.877	34.8	45.9	.529	.423	2.64	2.58	14.37	13.51	10.03	9.39	.89	.92
Dec. 5, 1922	.893	.869	30.7	37.7	.550	.338	3.30	3.08	12.04	11.35	8.39	7.74	1.38	1.22
Feb. 19, 1923	.858	.861	38.2	41.9	------	------	2.67	3.10	14.26	14.05	10.09	10.57	1.01	1.02
Feb. 14, 1924	.898	.878	31.6	37.6	------	------	2.61	3.21	13.34	14.11	9.72	10.11	.97	1.12
Dec. 1, 1924	.890	.870	34.1	38.1	.592	.275	2.78	3.14	12.43	11.87	8.55	7.68	1.24	1.20
Nov. 30, 1925	.902	.845	30.2	38.0	.571	.423	2.90	3.02	11.96	10.52	8.35	7.14	1.29	1.20
Mar. 2, 1926	------	------	33.5	42.4	.529	.423	2.64	2.58	14.50	13.56	10.59	9.38	.91	.91
Average	.882	.866	33.9	41.9	.566	.381	2.76	3.06	13.08	13.04	9.37	9.12	1.08	1.12

GOLDEN NUGGET, YELLOW THOMSON, AND BUCKEYE STRAINS

In many ways the fruit of the Golden Nugget, Yellow Thomson, and Buckeye strains resemble closely those of the Thomson strain. They differ chiefly from that strain in the color of the peel and in having fewer oil cells. The latter characteristic gives them a smooth satinlike appearance. All these strains produce some fruits that have on the peel narrow streaks of red, resembling the color of the Thomson or Washington fruit.

In oil content and insoluble solids these fruits are like the Thomson fruits, but they are uniformly more acid. They were compared with the Thomsons, as with few exceptions the differences shown would be even greater if the Washington strain had been used. There were also more instances where the progeny trees available for sampling were of common parentage with the available Thomson trees. The trees of the Buckeye were of common parentage with the Thomson trees with which they were compared, and the same relation existed between the Golden Nugget trees and the comparable Thomson trees. The Yellow Thomson trees were from two parents, one a Thomson of common parentage, the other a Washington-strain tree that bore no Thomson-strain fruit.

It is apparent, therefore, that comparison between each of these three strains and the Thomson strain was in most cases between trees of common parentage, but comparisons between the three strains themselves were based on samples from trees not having common parentage.

The striking peculiarity of the composition of this group is the very low percentage of oil which the fruits contain. The Buckeye and Yellow Thomson had only about 20 per cent of the oil contained in the fruit of the Thomson samples, and would therefore have about 10 per cent of that of the Washington-strain fruits. In each instance the odds are more than 10,000 to 1 that the differences shown are significant. Like odds exist that the Golden Nugget has more oil than either the Buckeye or Yellow Thomson.

As a whole, the group has the woody pulp common to the Thomson strain. The odds would undoubtedly be very high that each member differs in this respect from the Washington strain. Within the group the odds are less than 100 to 1 that any of these strains has more insoluble solids than the Thomson, but are about 800 to 1 that the Buckeye has more than the Golden Nugget.

In acidity of the juice the group is relatively higher than the Thomson. The odds are more than 750 to 1 that the juice of the Buckeye is more acid, 60 to 1 that the Golden Nugget is higher in acid, and 10,000 to 1 that the Yellow Thomson is. The odds are also high that the Buckeye is more acid than either the Golden Nugget or Yellow Thomson.

The Golden Nugget strain had less peel than the others, but the differences were not significant except in the case of the Buckeye, where the odds in its favor are 800 to 1, although the data show some reversals of the tendency. Table 9 shows the comparison between each strain and the Thomson strain, and also the relation between the individual strains of the group.

TABLE 9.—*Comparison of the composition of the Yellow Thomson, Golden Nugget, and Buckeye strains and of each of these strains with the Thomson strain*

YELLOW THOMSON AND GOLDEN NUGGET STRAINS

Date	Whole fruit						Pulp		Juice					
	Specific gravity		Peel		Oil		Insoluble solids		Soluble solids		Sugar		Acid	
	Yellow Thomson	Golden Nugget	Yellow Thomson	Golden Nugget	Yellow Thomson	Golden Nugget	Yellow Thomson	Golden Nugget	Yellow Thomson	Golden Nugget	Yellow Thomson	Golden Nugget	Yellow Thomson	Golden Nugget
			P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Jan. 9, 1923	0.878	0.896	30.8	31.3	0.063	0.106	2.83	2.66	12.56	11.39	9.26	8.91	1.14	0.81
Feb. 19, 1923	.878	.893	36.2	32.1	.042	.106	2.56	2.51	14.13	12.74	10.04	9.57	1.06	.74
Feb. 14, 1924	.895	.911	25.3	28.7	.063	.085	2.67	2.78	14.20	13.82	10.20	9.98	1.16	.91
Dec. 1, 1924	.907	.914	27.5	26.1	.042	.085	2.96	2.66	12.74	12.16	8.68	8.50	1.39	1.03
Nov. 30, 1925	.876	.903	30.2	25.3	.042	.085	3.12	2.97	11.96	12.10	8.35	8.68	1.34	1.11
Mar. 2, 1926	.902	.929	32.0	29.3	.042	.085	2.73	2.51	14.19	14.77	9.77	10.11	1.03	.79
Dec. 5, 1922	.872	.868	33.3	32.6	.064	.106	2.95	3.16	10.53	10.98	7.65	7.61	.98	1.12
Feb. 19, 1923	.861	.844	39.3	39.1	.042	.085	2.95	2.87	13.86	13.93	9.96	10.18	.80	.86
Feb. 14, 1924	.905	.892	31.6	29.0	.085	.085	2.90	2.85	14.33	14.72	10.80	10.24	.88	1.02
Dec. 1, 1924	.904	.890	29.3	28.8	.063	.085	2.85	3.01	12.31	11.63	8.29	7.77	1.06	1.02
Mar. 2, 1926	.897	.905	31.4	34.6	.042	.063	2.40	2.57	13.69	13.71	9.43	9.57	.80	.81
Jan. 9, 1923	.871	.869	37.8	35.0	.063	.106	2.90	2.67	12.00	12.24	9.13	9.13	.96	.93
Feb. 19, 1923	.871	.859	37.5	39.2	------	------	2.95	2.87	13.54	14.36	9.96	10.18	.93	.95
Feb. 14, 1924	.892	.890	30.4	29.6	------	------	2.90	2.85	13.97	14.01	10.80	10.24	.84	.95
Dec. 1, 1924	.888	.888	30.3	28.0	.085	.085	2.87	2.85	12.57	11.89	8.55	8.16	1.07	1.09
Mar. 2, 1926	.915	.909	34.7	32.5	.042	.063	2.40	2.57	13.79	14.27	9.84	7.82	.80	.86
Average	.888	.891	32.3	31.3	.056	.088	2.81	2.77	13.15	13.04	9.42	9.17	1.02	.94

YELLOW THOMSON AND BUCKEYE STRAINS

	Yellow Thomson	Buckeye	Yellow Thomson	Buckeye	Yellow Thomson	Buckeye	Yellow Thomson	Buckeye	Yellow Thomson	Buckeye	Yellow Thomson	Buckeye	Yellow Thomson	Buckeye
Jan. 9, 1923	0.871	0.864	37.8	37.3	0.063	0.063	2.90	3.11	12.00	13.17	9.13	9.91	0.96	0.98
Feb. 19, 1923	.871	.875	37.5	36.4	------	------	2.95	2.72	13.54	13.96	9.96	10.39	.93	.92
Feb. 14, 1924	.892	.893	30.4	33.5	------	------	2.90	3.27	13.97	14.42	10.80	10.89	.84	1.02
Dec. 1, 1924	.888	.904	30.3	32.1	.085	.063	2.87	3.27	12.57	13.59	8.55	9.46	1.07	1.18
Mar. 2, 1926	.915	.919	34.7	34.9	.042	.042	2.40	2.83	13.79	14.92	9.84	10.72	.80	.85
Dec. 5, 1922	.872	.890	33.3	31.6	.064	.064	2.95	3.24	10.53	11.39	7.65	8.48	.98	1.17
Feb. 19, 1923	.861	.875	39.3	37.0	------	------	2.95	2.72	13.86	13.67	9.96	10.39	.80	.88
Feb. 14, 1924	.905	.896	31.6	32.6	------	------	2.90	3.27	14.33	14.21	10.80	10.89	.88	.91
Dec. 1, 1924	.904	.909	29.3	30.2	.063	.063	2.85	3.18	12.31	13.19	8.29	8.98	1.06	1.18
Nov. 30, 1925	.880	.889	29.3	30.3	.064	.064	2.94	3.15	10.96	11.88	7.79	8.94	1.03	1.16
Mar. 2, 1926	.897	.914	31.4	33.5	.042	.042	2.40	2.83	13.69	15.57	9.43	11.16	.80	.91
Average	.887	.893	33.2	33.6	.060	.057	2.82	3.05	12.87	13.63	9.29	10.02	.92	1.01

TABLE 9.—*Comparison of the composition of the Yellow Thomson, Golden Nugget, and Buckeye strains and of each of these strains with the Thomson strain*—Con.

BUCKEYE AND GOLDEN NUGGET STRAINS

Date	Whole fruit						Pulp		Juice					
	Specific gravity		Peel		Oil		Insoluble solids		Soluble solids		Sugar		Acid	
	Buckeye	Golden Nugget	Buckeye	Golden Nugget	Buckeye	Golden Nugget	Buckeye	Golden Nugget	Buckeye	Golden Nugget	Buckeye	Golden Nugget	Buckeye	Golden Nugget
Dec. 5, 1922	0.890	0.868	31.6	32.6	0.064	0.106	3.24	3.16	11.39	10.98	8.48	7.61	1.17	1.12
Feb. 19, 1923	.875	.844	37.0	39.1	------	------	2.72	2.87	13.67	13.93	10.39	10.18	.88	.86
Feb. 14, 1924	.896	.892	32.6	29.0	------	------	3.27	2.85	14.21	14.72	10.89	10.24	.91	1.02
Dec. 1, 1924	.909	.890	30.2	28.8	.063	.085	3.18	3.01	13.19	11.63	8.98	7.77	1.18	1.02
Mar. 2, 1926	.914	.905	33.5	34.6	.042	.063	2.83	2.57	15.57	13.71	11.16	9.57	.91	.81
Jan. 9, 1923	.864	.896	37.3	31.3	.063	.106	3.11	2.66	13.17	11.39	9.91	8.91	.98	.81
Feb. 19, 1923	.875	.893	36.4	32.1	.085	.106	2.72	2.51	13.96	12.74	10.39	9.57	.92	.74
Feb. 14, 1924	.893	.911	33.5	28.7	.063	.085	3.27	2.78	14.42	13.82	10.89	9.98	1.02	.91
Dec. 1, 1924	.904	.914	32.1	26.1	.063	.085	3.27	2.66	13.59	12.16	9.46	8.50	1.18	1.03
Nov. 30, 1925	.897	.903	30.1	25.3	.064	.085	3.15	2.97	12.08	12.10	8.68	8.68	1.14	1.11
Mar. 2, 1926	.919	.929	34.9	29.3	.042	.085	2.83	2.51	14.92	11.77	10.72	10.11	.85	.79
Average	.894	.895	33.6	30.6	.061	.090	3.05	2.78	13.65	12.90	10.00	9.19	1.01	.93

THOMSON AND YELLOW THOMSON STRAINS

Date	Thomson	Yellow Thomson	Thomson	Yellow Thomson	Thomson	Yellow Thomson	Thomson	Yellow Thomson	Thomson	Yellow Thomson	Thomson	Yellow Thomson	Thomson	Yellow Thomson
Jan. 9, 1923	0.853	0.871	35.6	37.8	0.338	0.063	2.87	2.90	11.89	12.00	9.04	9.13	0.78	0.96
Feb. 19, 1923	.866	.871	34.2	37.5	------	------	2.78	2.95	13.32	13.54	10.31	9.96	.74	.93
Feb. 14, 1924	.889	.892	33.3	30.4	------	------	2.76	2.90	13.90	13.97	10.59	10.80	.80	.84
Dec. 1, 1924	.888	.888	33.0	30.3	.402	.085	3.07	2.87	12.75	12.57	8.26	8.55	1.07	1.07
Mar. 2, 1926	.916	.915	33.6	34.7	.360	.042	2.63	2.40	15.24	13.79	8.26	9.84	.72	.80
Dec. 5, 1922	.888	.872	31.0	33.3	------	------	3.11	2.95	11.08	10.53	8.44	7.65	.96	.98
Feb. 19, 1923	.881	.861	35.3	39.3	------	------	2.78	2.95	13.54	13.86	10.31	9.96	.80	.80
Feb. 14, 1924	.908	.905	29.0	31.6	------	------	2.76	2.90	14.13	14.33	10.59	10.80	.79	.88
Jan. 1, 1924	.903	.904	30.0	29.3	.381	.063	2.86	2.85	12.48	12.31	8.81	8.29	1.11	1.06
Nov. 30, 1925	.887	.880	30.8	29.3	.432	.064	3.00	2.94	11.53	10.96	8.11	7.79	1.07	1.03
Mar. 2, 1926	.923	.897	33.1	31.4	.360	.042	2.63	2.40	14.34	13.69	10.17	9.43	.78	.80
Feb. 19, 1923	.864	.878	39.1	36.2	.254	.042	2.72	2.56	15.68	14.13	10.92	10.04	1.01	1.06
Feb. 14, 1924	.898	.895	33.6	24.3	.296	.063	3.10	2.67	14.26	14.20	10.28	10.20	.90	1.16
Dec. 1, 1924	.900	.907	32.2	27.5	.360	.042	3.12	2.96	12.40	12.74	8.50	8.68	1.10	1.39
Nov. 30, 1925	.876	.893	30.6	30.2	.275	.042	2.98	3.12	11.48	11.96	8.45	8.35	1.08	1.34
Mar. 2, 1926	.902	.912	35.8	32.0	.296	.042	2.78	2.73	15.04	14.19	10.88	9.77	.77	1.03
Dec. 5, 1922	.861	.882	34.1	30.0	------	------	3.56	3.62	11.81	11.85	8.93	8.04	1.08	1.21
Feb. 19, 1923	.856	.876	39.0	34.6	------	------	2.72	2.56	13.88	14.05	10.92	10.04	.85	1.04
Feb. 14, 1924	.891	.899	32.6	25.9	------	------	3.10	2.67	13.53	14.25	10.28	10.20	.90	1.17
Dec. 1, 1924	.911	.891	30.1	26.0	.317	.042	2.59	2.74	11.91	12.35	8.20	8.55	.98	1.24
Nov. 30, 1925	.885	.869	31.0	29.3	.275	.042	2.98	3.12	11.33	12.08	8.20	8.34	.98	1.34
Mar. 2, 1926	.901	.903	34.2	31.6	.296	.042	2.78	2.73	14.97	13.99	9.90	9.83	.74	1.03
Average	.889	.889	33.2	31.5	.331	.051	2.89	2.84	13.20	13.06	9.47	9.28	.91	1.05

TABLE 9.—*Comparison of the composition of the Yellow Thomson, Golden Nugget, and Buckeye strains and of each of these strains with the Thomson strain*—Con.

THOMSON AND GOLDEN NUGGET STRAINS

Date	Whole fruit						Pulp		Juice					
	Specific gravity		Peel		Oil		Insoluble solids		Soluble solids		Sugar		Acid	
	Thomson	Golden Nugget	Thomson	Golden Nugget	Thomson	Golden Nugget	Thomson	Golden Nugget	Thomson	Golden Nugget	Thomson	Golden Nugget	Thomson	Golden Nugget
Apr. 1, 1915	0.9285	0.9307	21.28	18.78	0.057	0.016	2.30	2.29	15.06	14.91	10.91	10.00	0.65	0.60
Apr. 7, 1916	.8994	.8995	21.73	23.76	.200	.000	2.58	2.78	14.47	14.50	11.14	11.18	.59	.59
Apr. 7, 1916	.9075	.9370	25.51	20.56	------	------	2.80	3.10	14.57	14.86	11.28	11.53	.66	.74
Dec. 6, 1922	.902	.895	32.6	26.2	.296	.085	4.23	4.03	13.97	12.97	12.45	12.19	1.01	1.20
Feb. 14, 1924	.932	.930	24.0	22.6	.338	.296	3.33	3.49	16.74	16.36	------	------	1.05	1.11
Jan. 9, 1923	.883	.869	38.3	35.0	.423	.106	2.88	2.67	11.91	12.24	9.00	9.13	.83	.84
Feb. 19, 1923	.853	.852	38.5	39.2	.338	.085	2.63	2.87	13.34	14.14	9.91	10.18	1.04	1.06
Feb. 14, 1924	.912	.891	28.8	29.3	.294	.085	2.62	2.85	13.36	14.36	9.68	10.24	.84	.98
Dec. 1, 1924	.899	.889	30.4	28.4	.296	.085	2.59	2.93	12.02	11.76	8.37	7.96	.83	.90
Mar. 2, 1926	.900	.907	36.6	33.6	.233	.063	2.01	2.57	13.91	13.99	9.53	8.70	.88	.93
Average	.9016	.9000	30.07	27.74	.275	.091	2.80	2.96	13.94	14.01	10.25	10.12	.84	.89

THOMSON AND BUCKEYE STRAINS

Date	Thomson	Buckeye	Thomson	Buckeye	Thomson	Buckeye	Thomson	Buckeye	Thomson	Buckeye	Thomson	Buckeye	Thomson	Buckeye
Dec. 5, 1922	0.870	0.890	33.5	31.6	------	------	3.08	3.24	11.21	11.39	8.18	8.48	0.95	1.17
Feb. 19, 1923	.877	.875	36.3	36.7	0.381	0.085	2.76	2.72	14.16	13.82	10.61	10.39	.88	.90
Feb. 14, 1924	.908	.894	29.4	33.0	.212	.063	2.65	3.27	13.86	14.32	10.32	10.89	.77	.96
Dec. 1, 1924	.907	.906	30.4	31.2	.317	.063	2.91	3.22	13.01	13.39	9.41	9.22	1.06	1.18
Nov. 30, 1925	.900	.893	28.7	30.2	.296	.064	2.95	3.15	11.73	11.98	8.77	8.81	.95	1.15
Mar. 2, 1926	.912	.916	33.3	34.2	.338	.042	2.45	2.83	14.98	15.24	10.67	10.94	.75	.88
Average	.896	.896	31.9	32.8	.309	.063	2.80	3.07	13.16	13.36	9.66	9.79	.89	1.04

FLATTENED THOMSON, OVAL THOMSON, FLUTED THOMSON, AND RIBBED THOMSON STRAINS

Unlike the preceding group, the composition of the Flattened Thomson, Oval Thomson, Fluted Thomson, and Ribbed Thomson strains did not differ in any one particular from that of the normal Thomson strain. As a matter of fact, the chief difference seemed to be in shape or in some peculiarity of the peel. None of the trees from which these samples came were of common parentage within the last few generations. Comparisons were made with normal Thomson strain trees growing near by.

The Flattened Thomson (*9*) type occurs as a variant on both Washington and Thomson trees. It differs from these strains in shape, being flattened at both stem and navel end. In composition it differed but little from the normal Thomson. The chief difference was in the acidity of the juice, the odds being about 475 to 1 that the juice is more acid.

The fruits of the Oval Thomson strain differ from those of the normal Thomson mainly in shape, being elliptical or oval instead of the normal obovate shape. The juice of the comparable samples of this strain was sweeter than that from the Thomson samples. The odds are 450 to 1 that the soluble solids are higher and 100 to 1 that the sugar is higher.

The fruits of the Fluted Thomson strain have widely separated undulating smooth and regular flutes with a decided tendency to deep creases at the stem end. In color, shape, texture, and composition, they resemble the Thomson strain. The chief difference in composition was in the acidity of the juice, the odds being 130 to 1 that the fluted strain is more acid.

Fruits of the Ribbed Thomson strain (7) are more sharply ridged than those of the Fluted Thomson strain, and do not have the tendency to crease at the stem end. Very little difference in composition was shown between fruits of this strain and the Thomson. The pulp contained slightly more soluble solids, and the juice was somewhat more acid, but the odds that these differences are significant are not high in either case.

A few differences that have not been brought out by the comparisons already made were apparent between these strains. The Fluted Thomson strain had considerably more oil than the Ribbed Thomson, the odds being about 832 to 1 that this difference is significant. Odds are also more than 10,000 to 1 that the average difference of 0.71 per cent in the quantity of insoluble solids in the two strains is significant. The juice of the Oval Thomson strain was higher in soluble solids and sugar, but the juice of the other strains was like that of the normal Thomson in this respect, so that it is not necessary to dwell upon these differences. The Flattened Thomson and Ribbed Thomson strains contained more acid in the juice than the other strains, and the odds are high that they differ from the Oval Thomson strain in this respect. In Table 10 the composition of each strain in this group is compared with that of the Thomson strain.

Table 10.—*Comparison of the composition of the Thomson strain with that of the Flattened Thomson, Oval Thomson, Fluted Thomson, and Ribbed Thomson strains*

THOMSON AND FLATTENED THOMSON STRAINS

Date	Whole fruit						Pulp		Juice					
	Specific gravity		Peel		Oil		Insoluble solids		Insoluble solids		Sugar		Acid	
	Thomson	Flattened Thomson	Thomson	Flattened Thomson	Thomson	Flattened Thomson	Thomson	Flattened Thomson	Thomson	Flattened Thomson	Thomson	Flattened Thomson	Thomson	Flattened Thomson
			P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Nov. 30, 1925	0.887	0.915	30.7	27.8	0.254	0.275	2.76	2.86	11.69	10.22	8.27	6.89	0.97	1.07
Mar. 2, 1926	.967	.887	32.4	32.9	.212	.254	2.36	2.27	13.66	13.76	10.05	9.53	.75	.76
Dec. 7, 1926	.881	.864	33.8	33.4	.264	.338	3.33	3.08	14.57	13.87	10.43	9.53	1.34	1.38
Jan. 10, 1927	.879	.869	35.2	34.2	.251	.275	3.03	2.81	14.76	14.49	11.05	10.13	1.06	1.25
Feb. 24, 1927	.878	.870	37.2	33.3	.275	.207	2.88	2.55	15.71	15.33	11.63	11.07	.91	1.02
Nov. 30, 1925	.878	.866	31.1	30.2	.254	.275	2.76	2.86	10.82	10.39	8.30	6.97	.95	1.01
Dec. 7, 1926	.882	.875	32.2	32.3	.381	.296	3.05	3.28	13.63	13.67	9.59	9.85	1.23	1.44
Jan. 10, 1927	.881	.868	34.5	33.7	.222	.286	3.05	3.03	13.99	14.09	10.20	10.35	1.03	1.25
Feb. 24, 1927	.891	.857	33.5	38.0	.212	.178	2.74	2.92	14.81	15.27	10.42	11.18	.99	1.06
Average	.885	.875	33.4	32.9	.259	.265	2.88	2.85	13.74	13.45	9.99	9.50	1.03	1.14

TABLE 10.—*Comparison of the composition of the Thompson strain with that of the Flattened Thomson, Oval Thomson, Fluted Thomson, and Ribbed Thomson strains*—Continued

THOMSON AND OVAL THOMSON STRAINS

Date	Whole fruit						Pulp		Juice					
	Specific gravity		Peel		Oil		Insoluble solids		Soluble solids		Sugar		Acid	
	Thomson	Oval Thomson	Thomson	Oval Thomson	Thomson	Oval Thomson	Thomson	Oval Thomson	Thomson	Oval Thomson	Thomson	Oval Thomson	Thomson	Oval Thomson
Nov. 30, 1925	0.887	0.882	30.7	31.2	0.254	0.233	2.76	3.05	11.69	12.03	8.27	9.01	0.97	1.02
Mar. 2, 1926	.907	.899	32.4	35.9	.212	.254	2.36	2.60	13.66	15.15	10.05	10.92	.75	.84
Dec. 7, 1926	.881	.888	33.8	35.3	.264	.338	3.33	3.64	14.57	14.87	10.43	10.67	1.34	1.28
Jan. 10, 1927	.879	.886	35.2	36.8	.254	.233	3.03	3.26	14.76	15.37	11.05	11.33	1.06	1.11
Feb. 24, 1927	.878	.897	37.2	38.2	.275	.233	2.88	2.99	15.71	16.19	11.63	11.66	.91	.97
Nov. 30, 1925	.878	.879	31.1	30.5	.254	.233	2.76	3.05	10.82	11.32	8.30	8.29	.95	.95
Mar. 2, 1926	.904	.899	34.2	33.7	.212	.254	2.36	2.60	14.22	14.67	10.13	10.27	.78	.75
Dec. 7, 1926	.882	.883	32.2	32.4	.381	.296	3.05	3.19	13.63	13.87	9.59	9.73	1.23	1.22
Jan. 10, 1927	.881	.880	34.5	32.8	.222	.275	3.05	2.84	13.99	14.24	10.20	10.14	1.03	1.05
Feb. 24, 1927	.891	.883	33.5	35.4	.212	.212	2.74	2.71	14.81	14.89	10.42	10.84	.99	.89
Average	.887	.887	33.5	34.2	.254	.256	2.83	2.99	13.79	14.26	10.01	10.29	1.00	1.01

THOMSON AND FLUTED THOMSON STRAINS

Date	Thomson	Fluted Thomson	Thomson	Fluted Thomson	Thomson	Fluted Thomson	Thomson	Fluted Thomson	Thomson	Fluted Thomson	Thomson	Fluted Thomson	Thomson	Fluted Thomson
Nov. 30, 1925	0.887	0.882	30.7	33.4	0.254	0.381	2.76	2.99	11.69	11.36	8.27	8.37	0.97	1.10
Mar. 2, 1926	.907	.897	32.4	38.8	.212	.338	2.36	2.42	13.66	14.05	10.05	9.99	.75	.85
Dec. 7, 1926	.881	.879	33.8	34.3	.264	.592	3.33	3.22	14.57	14.63	10.43	10.63	1.34	1.52
Jan. 10, 1927	.879	.882	35.2	35.8	.254	.381	3.03	2.85	14.76	14.77	11.05	11.00	1.06	1.13
Feb. 24, 1927	.878	.884	37.2	36.9	.275	.254	2.88	2.84	15.71	15.73	11.63	11.52	.91	1.01
Nov. 30, 1925	.878	.883	31.1	32.2	.254	.381	2.76	2.99	10.82	11.15	8.30	8.04	.95	1.05
Mar. 2, 1926	.904	.899	34.2	34.9	.212	.338	2.36	2.42	14.22	14.16	10.13	9.88	.78	.80
Dec. 7, 1926	.882	.884	32.2	31.9	.381	.338	3.05	3.01	13.63	13.63	9.59	9.23	1.23	1.26
Jan. 10, 1927	.881	.872	34.5	33.8	.222	.201	3.05	2.67	13.99	13.88	10.20	10.20	1.03	1.08
Feb. 24, 1927	.891	.878	33.5	34.7	.212	.212	2.74	2.57	14.81	14.93	10.42	11.25	.99	.89
Average	.887	.884	33.5	34.7	.254	.342	2.83	2.80	13.79	13.83	10.01	10.01	1.00	1.07

THOMSON AND RIBBED THOMSON STRAINS

Date	Thomson	Ribbed Thomson	Thomson	Ribbed Thomson	Thomson	Ribbed Thomson	Thomson	Ribbed Thomson	Thomson	Ribbed Thomson	Thomson	Ribbed Thomson	Thomson	Ribbed Thomson
Nov. 30, 1925	0.873	0.872	32.3	32.3	0.338	0.254	3.05	3.79	11.70	11.15	8.52	8.38	0.95	1.20
Mar. 2, 1926	.898	.899	34.6	36.8	.254	.254	2.92	2.95	14.77	15.64	10.53	11.72	.71	.88
Dec. 7, 1926	.861	.881	36.0	36.7	.338	.275	3.29	4.24	13.46	13.63	9.39	10.47	1.23	1.33
Jan. 10, 1927	.878	.898	34.6	34.1	.275	.212	2.85	3.68	14.43	14.41	10.08	10.60	1.04	1.34
Feb. 24, 1927	.874	.856	36.8	39.9	.190	.233	2.06	3.23	15.09	15.48	11.04	11.69	.90	.95
Nov. 30, 1925	.884	.887	34.4	30.6	.338	.254	3.05	3.79	11.76	11.50	8.86	7.95	1.16	1.21
Mar. 2, 1926	.912	.901	34.8	33.4	.254	.254	2.92	2.95	15.44	15.24	10.86	11.22	.88	.85
Dec. 7, 1926	.892	.881	37.5	34.0	.317	.212	3.82	3.93	14.87	13.26	10.78	9.65	1.54	1.43
Jan. 10, 1927	.902	.884	37.5	34.0	.233	.148	3.51	3.51	14.73	14.27	11.78	10.40	1.25	1.29
Feb. 24, 1927	.894	.842	39.7	34.4	.169	.148	3.35	3.06	16.33	14.24	12.01	10.66	1.03	.96
Average	.887	.880	35.8	34.6	.271	.224	3.08	3.51	14.26	13.88	10.38	10.27	1.07	1.14

SMOOTH PEAR-SHAPED THOMSON STRAIN

The fruits of the Smooth Pear-shaped Thomson strain are usually small and distinctly pyriform in shape, with rather a long collar or neck at the stem end. The rind is coarse in texture and yellowish orange in color. This strain was not included in the last grouping because of its unusually low content of peel. There was a mean difference in specific gravity between it and the normal Thomson of 0.026, with odds of more than 10,000 to 1 that the difference exists, no instance in the 10 showing a reversal of the tendency. The odds are also more than 500 to 1 that the average difference of 3.8 per cent in the percentage of peel is significant, as in no instance did the normal-strain samples have less peel. As will be seen from Table 11, in other respects the strain differed but little from the Thomson strain.

TABLE 11.—*Comparison of the composition of the normal Thomson and of the Smooth Pear-shaped Thomson strains*

Date	Whole fruit						Pulp		Juice					
	Specific gravity		Peel		Oil		Insoluble solids		Soluble solids		Sugar		Acid	
	Thomson	Smooth Pear-shaped Thomson	Thomson	Smooth Pear-shaped Thomson	Thomson	Smooth Pear-shaped Thomson	Thomson	Smooth Pear-shaped Thomson	Thomson	Smooth Pear-shaped Thomson	Thomson	Smooth Pear-shaped Thomson	Thomson	Smooth Pear-shaped Thomson
			P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Nov. 30, 1925	0.887	0.898	30.7	30.0	0.254	0.275	2.76	3.33	11.69	11.07	8.27	8.04	0.97	0.94
Mar. 2, 1926	.907	.916	32.4	31.5	.212	.508	2.36	2.77	13.66	13.68	10.05	9.69	.75	.76
Dec. 7, 1926	.881	.910	33.8	27.4	.264	.317	3.33	3.11	14.57	12.46	10.43	8.44	1.34	1.15
Jan. 10, 1927	.879	.917	35.2	26.6	.254	.243	3.03	2.62	14.76	13.17	11.05	9.40	1.06	1.04
Feb. 14, 1927	.878	.905	37.2	30.0	.275	.275	2.88	2.71	15.71	14.22	11.63	10.08	0.91	0.78
Nov. 30, 1925	.878	.900	31.1	30.5	.254	.275	2.76	3.33	10.82	11.37	8.30	8.37	.95	1.07
Mar. 2, 1926	.904	.922	34.2	29.7	.212	.508	2.36	2.77	14.22	14.44	10.13	10.54	.78	0.81
Dec. 7, 1926	.882	.916	32.2	30.3	.381	.317	3.05	4.27	13.63	13.26	9.59	9.81	1.23	1.33
Jan. 10, 1927	.881	.923	34.5	28.9	.222	.233	3.05	3.39	13.99	14.37	10.20	10.86	1.03	1.18
Feb. 24, 1927	.891	.919	33.5	31.9	.212	.222	2.74	2.99	14.81	15.47	10.42	11.28	0.99	0.98
Average	.887	.913	33.5	29.7	.254	.317	2.83	3.13	13.79	13.35	10.01	9.65	1.00	1.00

SHEEPNOSE THOMSON STRAIN

The fruits of the Sheepnose Thomson strain (*8*) are small and oval, with a peculiar and characteristic protrusion of the distal end, owing to the development of abnormally large inclosed navels or secondary oranges. The rind is coarse, and many of the fruits are wrinkled at the stem end.

This is a peculiar strain. The fruits are very thick-skinned, the skin contains a high percentage of oil, the pulp contains a high percentage of insoluble solids, and the juice has a low percentage of acid with a rather high percentage of sugar.

The odds are very high that the differences in content of peel between this strain and both the Thomson and Washington strains are significant. The oil content was also much greater than that of the Thomson, being even somewhat higher than that of the Washington. The edible portion of the fruit was even more woody than that of the Thomson, the odds being more than 10,000 to 1 that the difference in insoluble solids is significant.

The juice was sweet and nonacid. The odds are high that it is less acid than that of either of the other strains, and the odds are 200 to 1 that it is sweeter than that of the Thomson. Table 12 shows the comparison of the Sheepnose Thomson with the Thomson strain and the Washington strain.

TABLE 12.—*Comparison of the composition of the Sheepnose Thomson strain with that of the Thomson and the Washington strains*

Date	Whole fruit									Pulp		
	Specific gravity			Peel			Oil			Insoluble solids		
	Thomson	Sheepnose Thomson	Washington	Thomson	Sheepnose Thomson	Washington	Thomson	Sheepnose Thomson	Washington	Thomson	Sheepnose Thomson	Washington
				P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Nov. 30, 1925	0.887	0.870	0.895	30.7	46.2	29.6	0.251	0.592	0.465	2.76	3.83	2.53
Do	.878	.874	.882	31.1	44.9	32.6	.254	.592	.465	2.76	3.83	2.53
Mar. 2, 1926	.907	.901	.912	32.4	46.6	31.8	.212	.592	.486	2.36	2.66	2.29
Do	.904	.906	.905	34.2	42.1	34.0	.212	.592	.486	2.36	2.66	2.29
Dec. 7, 1926	.881	.873	.886	33.8	46.8	30.9	.264	.666	.465	3.33	3.92	2.62
Do	.882	.850	.882	32.2	47.4	34.8	.381	.582	.529	3.05	3.61	2.88
Jan. 10, 1927	.879	.886	.889	35.2	48.3	32.6	.254	.740	.455	3.03	3.81	2.08
Do	.881	.859	.899	31.5	48.8	33.6	.222	.486	.550	3.05	3.58	2.56
Feb. 24, 1927	.878	.889	.878	37.2	48.9	36.0	.275	.567	.423	2.88	3.36	2.23
Do	.891	.851	.882	33.5	49.3	38.8	.212	.465	.457	2.74	2.95	2.35
Average	.887	.876	.891	33.5	46.9	33.5	.254	.587	.478	2.83	3.42	2.44

Date	Juice								
	Soluble solids			Sugar			Acid		
	Thomson	Sheepnose Thomson	Washington	Thomson	Sheepnose Thomson	Washington	Thomson	Sheepnose Thomson	Washington
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Nov. 30, 1925	11.69	11.19	11.23	8.27	7.87	7.45	0.97	0.78	1.18
Do	10.82	11.09	11.22	8.30	8.13	7.87	.95	.75	.91
Mar. 2, 1926	13.66	15.03	13.70	10.05	10.93	9.79	.75	.58	.86
Do	14.22	14.63	14.00	10.13	10.94	9.88	.78	.54	1.19
Dec. 7, 1926	14.57	14.63	13.36	10.43	11.00	9.34	1.34	1.08	1.38
Do	13.63	13.56	13.89	9.59	10.06	9.89	1.23	.98	1.41
Jan. 10, 1927	14.76	14.00	13.46	11.05	12.02	9.81	1.06	.93	1.21
Do	13.99	13.89	14.39	10.20	10.67	10.39	1.03	.86	1.27
Feb. 24, 1927	15.71	16.57	14.06	11.63	12.46	9.99	.91	.74	.99
Do	14.81	14.63	15.29	10.42	10.85	11.03	.99	.63	1.08
Average	13.79	13.92	13.46	10.01	10.49	9.54	1.00	.79	1.15

SUMMARY AND CONCLUSIONS

The composition of 18 strains of the Washington Navel orange, isolated and described by Shamel, Scott, Pomeroy, and Caryl, has been studied. Pomologists noted the physical characteristics of these strains, such as size, shape, and color and texture of skin and pulp, as well as the habits of growth and yields, and proved that most of these are transmitted by vegetative propagation.

The study here reported revealed that differences in the chemical composition of strains exist and that these are inheritable. Some of course are closely connected with the physical differences; others are not. The differences generally found were in the quantities of peel, oil, insoluble solids, and acid. Less variation was found in the specific gravity of the fruits and in the soluble solids and sugar of the juice.

Strains of fruit with smooth skins usually contain only small quantities of oil. As a rule, the fruits of the strains having heavy peel are low in specific gravity, although this effect is modified by texture, hollow centers, and other factors. Strains having pulp with woody texture contain high percentages of insoluble solids.

Distinct inherited differences in composition between the Washington and Thomson strains were shown. A group of strains differing somewhat from the Thomson, but similar to it in many respects were shown to differ from the Washington strain very much as the Thomson strain differs. Other strains differed materially from the Thomson and only in minor respects from the Washington. A few strains differed from both the Washington and Thomson strains. The differences seemed to be more pronounced in fruits from the progeny trees than in those from the parent trees.

Great care was exercised in collecting samples so that a series of comparable couples would be available for comparison by the Student method. Such couples were also harvested on the same day and consisted of fruits true to type.

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UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

TESTS OF VARIOUS ALIPHATIC COMPOUNDS AS FUMIGANTS

By R. C. ROARK, *Principal Chemist in Charge, Insecticide Division, Chemical and Technological Research, Bureau of Chemistry and Soils*, and R. T. COTTON, *Senior Entomologist, Division of Stored-Product Insects, Bureau of Entomology*

CONTENTS

INTRODUCTION

The action of several organic compounds in the vapor phase upon rice weevils, flour beetles, granary weevils, and the Indian-meal moth was tested in a previous investigation,[1] and the results were reported in Department Bulletin 1313. The object of that investigation was to find a material free from the fire hazard of carbon disulphide that would be suitable for killing insects in grain. When the tests were made in glass flasks about 30 of the 100 compounds tested were more toxic to the rice weevil than was carbon disulphide. In tests made when grain was present, especially in box cars loaded with wheat, only ethyl acetate and ethyl formate gave uniformly good results, and because of its lower cost and greater availability the acetate was considered preferable to the formate. A mixture of 40 volumes of ethyl acetate and 60 volumes of carbon tetrachloride was recommended as a fumigant safe from fire hazard at fumigating temperatures, that is, up to 90° F.

In order to make ethyl acetate nonflammable at temperatures up to 122° F. (50° C.), however, the temperature at which the underwriters' laboratories conduct tests to determine whether a vapor will propagate a flame, it is necessary to add carbon tetrachloride to the

[1] NEIFERT, I. E., COOK, F. C., ROARK, R. C., TONKIN, W. H., BACK, E. A., and COTTON, R. T., FUMIGATION AGAINST GRAIN WEEVILS WITH VARIOUS VOLATILE ORGANIC COMPOUNDS. U. S. Dept. Agr. Bul. 1313, 40 p., illus. 1925.

extent of 70 per cent by volume of the mixture. Ethyl acetate has only a moderate toxicity to insects exposed to its vapor, and the addition of carbon tetrachloride, which has a low toxicity to insects, produces a mixture having an insecticidal value lower than that of ethyl acetate alone.

Furthermore, wheat that has been fumigated with the ethyl acetate mixture may have a sour odor, resulting from acetic acid formed by hydrolysis of the ethyl acetate. This odor is similar to that of fermenting grain, and sometimes causes the wheat to be classed as Sample grade.

The experiments herewith reported were conducted in order to develop effective fumigants more suitable for treating infested grain, and for use in fumigating against insects infesting foodstuffs, clothing, carpets, and furniture. Some of the compounds previously investigated and many additional organic compounds were thoroughly tested.

TESTS IN ONE-HALF LITER FLASKS

METHOD

In order to select the more promising fumigants from the large number of compounds to be tested, an initial series of tests was made in ½-liter Erlenmeyer flasks. By fumigating on a small scale it was possible to make 30 or 40 fumigations in a day and thus test possible fumigants more quickly than if trials were made on a large scale. On account of its resistance to fumigants the rice weevil (*Sitophilus oryza* L.) was used exclusively in these small-scale tests. The weevils were confined in cotton-stoppered glass vials containing cracked corn, 10 weevils to each vial. One, or in some cases two, of the vials were placed on the bottom of a ½-liter Erlenmeyer flask, 200 grams (approximately 250 c. c.) of wheat was put in, and the calculated quantity of fumigant was added. The flasks were made air-tight with rubber stoppers and allowed to stand 24 hours at room temperature, which averaged about 25° C. At the end of the 24-hour fumigation period the percentage of dead weevils was determined. To avoid reporting as dead any that were only stupefied, all specimens were reexamined after 24 hours and also after 48 hours. Many specimens were kept for 30 days after fumigation, but none revived after the 48-hour period. The percentage of dead weevils reported in Table 1 is that determined at the end of the 48-hour period.

This series of experiments differs from that reported in Department Bulletin No. 1313, in that all the fumigants were tested in the presence of wheat. Inasmuch as under practical fumigating conditions absorptive materials are always present, it was believed that tests in the presence of wheat, which has a great absorptive capacity for some vapors, would determine fumigants of low toxicity more quickly than if the tests were made in flasks containing no absorptive material.

The compounds selected for testing were obtained for the most part from the Eastman Kodak Co. A few materials were synthesized in the laboratory. In all cases, compounds of the highest possible purity procurable were used for these tests.

The liquid fumigants were applied by means of a pipette graduated to 0.01 c. c. The dosages are therefore known within 0.02 cubic centimeter per liter, which is equivalent to about 13 mg. per liter

(0.8 pound per 1,000 cubic feet) for a material of low specific gravity, such as *n*-pentane; or to about 66 mg. per liter (4 pounds per 1,000 cubic feet) for a material of high specific gravity, such as methylene iodide. The solid fumigants were weighed to the nearest milligram and added to the flasks. In general, in this series of tests, where the minimum lethal dosage of the fumigant was determined to within 0.01 c. c. per ½-liter flask, the results are accurate to within about 2 pounds per 1,000 cubic feet. For a more exact determination of the minimum lethal dosage of a fumigant, tests on a larger scale are necessary.

Each fumigant was tested from 5 to 30 times over a range of different concentrations. No fumigant was tested at a concentration of more than 0.5 c. c. per liter. Some fumigants killed 100 per cent of the weevils at the minimum dosage it was possible to employ, 0.02 c. c. per liter. In other cases many dosages were tried, and the minimum that killed 100 per cent of the weevils during an exposure of 24 hours was taken as the minimum lethal dosage.

As some fumigants were tested in quantities varying by 0.05 c. c. per ½-liter flask, the lethal dosage of these compounds is not known closer than 0.10 c. c. per liter. Only compounds of low toxicity, however, were tested in this way, as the object of this first series of tests was to select the fumigants worthy of trial on a large scale, rather than to determine the exact minimum lethal dosage of the compounds.

EXPERIMENTAL RESULTS

The results of the tests are given in Table 1, which presents in addition the following information regarding each fumigant: Empirical and structural formulas, synonyms, molecular weight, boiling point,[2] specific gravity,[2] concentration of fumigant, expressed in milligrams per liter, and percentage mortality of weevils after 24 hours' exposure.

[2] Data taken from NATIONAL RESEARCH COUNCIL. INTERNATIONAL CRITICAL TABLES OF NUMERICAL DATA, PHYSICS, CHEMISTRY AND TECHNOLOGY . . . v. 1, 415 p., illus., New York and London, 1926.

TABLE 1.—*Empirical formula, synonyms, structural formula, molecular weight, boiling point, specific gravity, concentration of fumigants, and percentage mortality of weevils after exposure for 24 hours*

Empirical formula	Compound with synonyms	Structural formula	Molecular weight	Boiling point at 76 mm.	Specific gravity 20°/4°	Minimum lethal dosage of fumigant	Weevils killed after exposure for 24 hours
				° *C.*		*Mg. per liter*	*Per cent*
C_5H_{12}	Pentane	$CH_3CH_2CH_2CH_2CH_3$	72.096	36.2	0.631	[1] 316	40
	(Mixture; largely *n*-pentane)						
	Amyl hydride						
	Pentan						
	Normales pentan						
	n-Pentan						
C_6H_{14}	*n*-Hexane	$CH_3CH_2CH_2CH_2CH_2CH_3$	86.108	69.0	.660	[1] 330	60
	Dipropyl						
	Hexan						
	Normales hexan						
	n-Hexan						
C_7H_{16}	*n*-Heptane	$CH_3(CH_2)_5CH_3$	100.12	98.4	.684	260	100
	Heptyl hydride						
	Methyl hexane						
	Dipropylmethane						
	Heptan						
	Normales heptan						
	n-Heptan						
C_8H_{18}	*n*-Octane	$CH_3(CH_2)_6CH_3$	114.144	124.6	.707	[1] 354	60
	Octan						
	Normales octan						
	n-Octan						
$C_{10}H_{22}$	Decane	$(CH_3)_2CH(CH_2)_4CH(CH_3)_2$	142.176	160.0	.722	[1] 361	0
	2, 7-Dimethyloctane						
	Di*iso*amyl						
	2.7-Dimethyl-octan						
C_5H_{10}	Amylene		70.077		.7	[1] 350	0
	Mixture of:						
	*Iso*propylethylene	$(CH_3)_2CHCH{=}CH_2$	20.2				
	Trimethylethylene	$(CH_3)_2C{=}CHCH_3$	38.4				
	as-Methylethylethylene	$CH_2{=}C(CH_3)C_2H_5$	31-33				
	2-Pentene	$CH_3CH_2CH{=}CHCH_3$	36				
	*Iso*pentane	$(CH_3)_2CHCH_2CH_3$	28				
	Käufliches Amylen						
	Gewöhnliches Fuselölamylen						
C_5H_{10}	Trimethylethylene	$(CH_3)_2C{=}CHCH_3$	70.077	38.4	.668	[1] 334	40
	2-Methyl-2-butene						
	Pental						

	Pentene						
	Amylene						
	*β-Iso*amylene						
	2-Methyl-buten-(2)						
	Trimethyl-Äthylen						
	β-Methyl-β-butylene						
C_8H_{16}	Octylene		112. 12	125	. 7197	1 360 [1]	70
	Caprylene						
	Mixture of:						
	α-Octylene (Octene-(1))	$CH_3(CH_2)_5CH{=}CH_2$.					
	β-Octylene (Octene-(2))	$CH_3(CH_2)_4CH{=}CH\ CH_3$.					
	Octylen						
	Caprylen						
	Mixture of:						
	Octen-(1) α-Octylen						
	Octen-(2) β-Octylen						
C_8H_{16}	Di*iso*butylene	$(CH_3)_3CCH{=}C(CH_3)_2$	112. 12	102. 6	. 715	215	100
	Di*iso*butylen						
CH_2Br_2	Methylene bromide	CH_2Br_2	173. 85	97. 8	2. 46	738	100
	Dibromomethane						
	Dibrommethan						
	Methylenbromid						
$CHBr_3$	Bromoform	$CHBr_3$	252. 76	150. 4	2. 89	231	100
	Tribromomethane						
	Methenylbromide						
	Formyl tribromide						
	Methenyl tribromide						
	Tribrommethan						
	Methenylbromid						
CBr_4	Carbon tetrabromide	CBr_4	331. 66	189. 5	3. 42	60	100
	Tetrabromomethane						
	Tetrabrommethan						
	Kohlenstofftetrabromid						
	Tetrabromkohlenstoff						
C_2H_5Br	Ethyl bromide	CH_3CH_2Br	108. 955	38. 0	1. 43	172	100
	Bromoethane						
	Monobromoethane						
	Hydrobromic ether						
	Bromic ether						
	Brom-äthan						
	Äthylbromid						
$C_2H_4Br_2$	Ethylidene bromide	CH_3CHBr_2	187. 86	110	2. 056	617	100
	1, 1-Dibromoethane						
	1, 1-Dibrom-äthan						
	Äthylidenbromid						
$C_2H_4Br_2$	Ethylene dibromide	CH_2BrCH_2Br	187. 86	131. 7	2. 182	87	100
	1, 2-Dibromoethane						
	Ethylene bromide						
	Dibromoethane						
	1, 2-Dibrom-äthan						

[1] The maximum dosage tested.

TABLE 1.—*Empirical formula, synonyms, structural formula, molecular weight, boiling point, specific gravity, concentration of fumigants, and percentage mortality of weevils after exposure for 24 hours*—Continued

Empirical formula	Compound with synonyms	Structural formula	Molecular weight	Boiling point at 760 mm.	Specific gravity 20°/4°	Minimum lethal dosage of fumigant	Weevils killed after exposure for 24 hours
				° *C.*		*Mg. per liter*	*Per cent*
$C_2H_4Br_2$	Ethylene dibromide—Continued						
	Äthylendibromid						
	Äthylenbromid						
$C_2H_2Br_4$	*sym.*-Tetrabromoethane	$CHBr_2CHBr_2$	345.68	151 (54 mm.)	2.964	[1] 1,482	0
	1, 1, 2, 2-Tetrabromoethane						
	Acetylene tetrabromide						
	Muthmann's liquid						
	1, 1, 2, 2-Tetrabrom äthan						
	Acetylentetrabromid						
C_3H_7Br	*n*-Propyl bromide	$CH_3CH_2CH_2Br$	122.97	70.9	1.353	81	100
	1-Bromopropane						
	1-Brom-propan						
	α-Brom-propan						
	n-Propylbromid						
	prim.-Propylbromid						
C_3H_7Br	*Iso*propyl bromide	$(CH_3)_2CHBr$	122.97	59.6	1.310	262	100
	2-Bromopropane						
	2-Brom-propan						
	β-Brom-propan						
	*Iso*propylbromid						
	sek. Propylbromid						
$C_3H_6Br_2$	Propylene bromide	$CH_3CHBrCH_2Br$	201.88	140	1.933	116	100
	1, 2-Dibromopropane						
	Propylene dibromide						
	1, 2-Dibrom-propan						
	Propylendibromid						
	Propylenbromid						
C_4H_9Br	*n*-Butyl bromide	$CH_3CH_2CH_2CH_2Br$	136.99	101.6	1.275	102	100
	1-Bromobutane						
	1-Brom-butan						
	n-Butylbromid						
	prim.-Butylbromid						
C_4H_9Br	*Iso*butyl bromide	$(CH_3)_2CHCH_2Br$	136.99	91.5	1.264	126	100
	1-Bromo-2-methylpropane						
	α-Bromo-*iso*butane						
	1-Brom-2-methylpropan						
	α-Brom-*iso*butan						
	*Iso*butylbromid						

C_4H_9Br	*sec.*-Butyl bromide 2-Bromobutane 2-Brom-butan *sek.*-Butylbromid	$CH_3CHBrCH_2CH_3$	136.99	91.3	1.251	375	100
C_4H_9Br	*tert.*-Butyl bromide 2-Bromo-2-methylpropane β-Bromo-*iso*butane 2-Brom-2-methylpropan β-Brom-*iso*butan *tert.*-Butylbromid	$(CH_3)_3CBr$	136.99	73.3	1.222	[2] 24	100
$C_4H_8Br_2$	α-Butylene bromide 1, 2-Dibromobutane α-Butylene dibromide 1, 2-Dibrom-butan α-Butylendibromid	$CH_3CH_2CHBrCH_2Br$	215.89	166	1.820	[1] 910	80
$C_4H_8Br_2$	β-Butylene bromide 2, 3-Dibromobutane β-Butylene dibromide Pseudobutylene dibromide 2, 3-Dibrom-butan β-Butylendibromid Pseudobutylendibromid	$CH_3CHBrCHBrCH_3$	215.89	158	1.83	[1] 915	80
$C_4H_8Br_2$	*Iso*butylene bromide 1, 2-Dibromo-2-methylpropane α β-Dibromo-*iso*butane Butylene *iso*bromide Dibromo*iso*butane 1, 2-Dibrom-2-methylpropan α β-Dibrom-*iso*butan *Iso*butylendibromid	$CH_3CBr(CH_3)CH_2Br$	215.89	149	1.759	281	100
$C_4H_7Br_3$	1, 2, 3-Tribromobutane 1, 2, 3-Tribrom-butan	$CH_3CHBrCHBrCH_2Br$	294.80	113 (19 mm.)	2.190	[1] 1,095	0
$C_5H_{11}Br$	*Iso*amyl bromide 4-Bromo-2-methylbutane 4-Brom-2-methylbutan *Iso*amylbromid	$(CH_3)_2CHCH_2CH_2Br$	151	121	1.215	146	100
C_3H_5Br	Allyl bromide 3-Bromopropylene 3-Bromopropene 3-Brom-propen-(1) Allylbromid	$CH_2{=}CHCH_2Br$	120.955	71.3	1.398	[2] 28	100
CH_2Cl_2	Methylene chloride Dichloromethane Methylene bichloride Dichlormethan Methylenchlorid	CH_2Cl_2	84.931	40.1	1.336	428	100
$CHCl_3$	Chloroform Trichloromethane Methenyl chloride Trichlormethan Methenylchlorid	$CHCl_3$	119.38	61.2	1.489	298	100

[1] The maximum dosage tested.

[2] The minimum concentration tested.

TABLE 1.—*Empirical formula, synonyms, structural formula, molecular weight, boiling point, specific gravity, concentration of fumigants, and percentage mortality of weevils after exposure for 24 hours*—Continued

Empirical formula	Compound with synonyms	Structural formula	Molecular weight	Boiling point at 760 mm.	Specific gravity 20°/4°	Minimum lethal dosage of fumigant	Weevils killed after exposure for 24 hours
				° C.		*Mg. per liter*	*Per cent*
CCl_4	Carbon tetrachloride Tetrachloromethane Perchloromethane Tetrachlormethan Kohlenstofftetrachlorid Tetrachlorkohlenstoff	CCl_4	153.83	76.8	1.595	638	100
$C_2H_4Cl_2$	Ethylidene chloride 1, 1-Dichloroethane 1. 1-Dichlor-äthan Äthylidenchlorid	CH_3CHCl_2	98.947	57.3	1.174	564	100
$C_2H_4Cl_2$	Ethylene dichloride 1, 2-Dichloroethane Ethylene chloride Elayl chloride Oil of the Dutch chemists Dichloroethane Dutch liquid 1. 2-Dichlor-äthan Äthylendichlorid Äthylenchlorid Öl der holländischen chemiker Elaylchlorid	CH_2Cl-CH_2Cl	98.947	83.7	1.257	226	100
C_2H_4BrCl	Ethylene chlorobromide 1-Bromo-2-chloroethane 2-Chlor-1-Brom-äthan Äthylenchlorobromid	CH_2Br-CH_2Cl	143.405	103.7	1.79	143	100
$C_2H_3Cl_3$	Trichloroethane 1, 1, 2-Trichloroethane Ethylene monochlorochloride Monochloroethylene chloride Monochlorinated Dutch liquid Vinyltrichloride 1. 1. 2-Trichlor-äthan	$CH_2ClCHCl_2$	133.397	113.5	1.443	404	100
$C_2H_2Cl_4$	*sym.*-Tetrachloroethane 1, 1, 2, 2-Tetrachloroethane Acetylene tetrachloride	$CHCl_2CHCl_2$	167.85	146.3	1.600	384	100

	Tetrachloroethane 1. 1. 2. 2-Tetrachlor-äthan Acetylentetrachlorid						
C_2HCl_5	Pentachloroethane Pentachlor-äthan	$CHCl_2CCl_3$	202. 298	162	1. 709	342	100
C_2Cl_6	Hexachloroethane Perchloroethane Carbon trichloride Carbon hexachloride Tetrachloroethylene dichloride Hexachlor-äthan Perchloräthan	CCl_3CCl_3	236. 75	185	2. 091	[1] 500	0
C_3H_7Cl	*n*-Propylchloride 1-Chloropropane α-Chloropropane 1-Chlor-propan α-Chlor-propan Propylchlorid	$CH_3CH_2CH_2Cl$	78. 512	46. 6	. 890	445	100
C_3H_7Cl	*Iso*propyl chloride 2-Chloropropane β-Chloropropane 2-Chlor-propan β-Chlor-propan *Iso*propylchlorid	$CH_3CHClCH_3$	78. 512	36. 5	. 860	430	100
$C_3H_6Cl_2$	Propylene chloride 1, 2-Dichloropropane Propylene dichloride α-β-Dichloropropane 1, 2-Dichlor-propan αβ-Dichlor-propan Propylendichlorid Propylenchlorid	$CH_3CHClCH_2Cl$	112. 962	96. 8	1. 166	140	100
$C_3H_6Cl_2$	Trimethylene chloride 1, 3-Dichloropropane Trimethylene dichloride 1, 3-Dichlor-propan αγ (oder ω.ω′-) Dichlor-propan Trimethylendichlorid Trimethylenchlorid	$ClCH_2CH_2CH_2Cl$	112. 962	125	1. 201	336	100
C_4H_9Cl	*n*-Butyl chloride 1-Chlorobutane 1-Chlor-butan *n*-Butylchlorid *prim.*-Butylchlorid	$CH_3CH_2CH_2CH_2Cl$	92. 527	78	. 884	265	100
C_4H_9Cl	*tert.*-Butyl chloride 2-Chloro-2-methylpropane β-Chlor-*iso*butane 2-Chlor-2-methylpropan β-Chlor-*iso*butan *tert.*-Butylchlorid Trimethylchlormethan	$(CH_3)_3CCl$	92. 527	51	. 840	34	100

[1] The maximum dosage tested.

TABLE 1.—*Empirical formula, synonyms, structural formula, molecular weight, boiling point, specific gravity, concentration of fumigants, and percentage mortality of weevils after exposure for 24 hours*—Continued

Empirical formula	Compound with synonyms	Structural formula	Molecular weight	Boiling point at 760 mm.	Specific gravity 20°/4°	Minimum lethal dosage of fumigant	Weevils killed after exposure for 24 hours
				° C.		*Mg. per liter*	*Per cent*
$C_4H_3Cl_2$	*n*-Butylidene chloride 1, 1-Dichlorobutane 1, 1-Dichlor-butan Butylidenchlorid	$CH_3CH_2CH_2CHCl_2$	126. 98	113 115	1. 1	220	100
$C_5H_{11}Cl$	*Iso*amyl chloride 4-Chloro-2-methylbutane 4-Chlor-2-methylbutan *Iso*amylchlorid	$(CH_3)_2CHCH_2CH_2Cl$	106. 54	99. 1	. 893	107	100
$C_2H_2Cl_2$	Dichloroethylene 1, 2-Dichloroethene Acetylene dichloride α β-Dichloroethylene 1.2-Dichlor-äthen *sym*.-oder α β-Dichlor-äthylen Acetylen-dichlorid	$CHCl{=}CHCl$	96. 931	[3] 55	1. 25	600	100
C_2HCl_3	Trichloroethylene Trichlor-äthan Trichlor-äthylen	$CHCl{=}CCl_2$	131. 38	88	1. 477	650	100
C_2Cl_4	Tetrachloroethylene Tetrachloroethene Perchlorethylene Carbon bichloride Carbon dichloride Tetrachlor-äthen Tetrachlor-äthylen Perchloräthylen	$Cl_2C{=}CCl_2$	165. 83	120. 8	1. 623	649	100
CH_3I	Methyl iodide Iodomethane Jodmethan Methyljodid	CH_3I	141. 96	42. 6	2. 279	[2] 46	100
CH_2I_2	Methylene iodide Diiodomethane Dijodmethan Methylenjodid	CH_2I_2	267. 88	[4] 180	3. 325	[2] 67	100
CHI_3	Iodoform Triiodomethane Methenyl iodide	CHI_3	393. 80	([4])	4. 1	[2] 500	0

	Formyl triiodide						
	Trijodmethan						
	Methenyljodid						
	Jodoform						
C_2H_5I	Ethyl iodide	CH_3CH_2I	155.97	72.2	1.933	[3] 39	100
	Iodoethane						
	Monoiodoethane						
	Jod-äthan						
	Äthyljodid						
C_3H_7I	*n*-Propyl iodide	$CH_3CH_2CH_2I$	169.99	102.4	1.747	[3] 35	100
	1-Iodopropane						
	α-Iodopropane						
	1-Jod-propan						
	α-Jod-propan						
	n-Propyljodid						
	prim.-Propyljodid						
C_3H_7I	*Iso*propyl iodide	$(CH_3)_2CHI$	169.99	89.5	1.703	68	100
	2-Iodopropane						
	β-Iodopropane						
	2-Jod-propan						
	β-Jod-propan						
	*Iso*propyljodid						
	sek.-Propyljodid						
C_4H_9I	*n*-Butyl iodide	$CH_3CH_2CH_2CH_2I$	184.00	127	1.617	97	100
	1-Iodobutane						
	1-Jod-butan						
	n-Butyljodid						
	prim.-Butyljodid						
C_4H_9I	*Iso*butyl iodide	$(CH_3)_2CHCH_2I$	184	120.4	1.605	64	100
	1-Iodo-2-methylpropane						
	α-Iodo-*iso*butane						
	1-Jod-2-methylpropan						
	α-Jod-*iso*butan						
	*Iso*butyljodid						
C_4H_9I	*sec.*-Butyl iodide	$CH_3CHICH_2CH_3$	184	117.5	1.595	64	100
	2-Iodobutane						
	Methylethylcarbiniodide						
	2-Jod-butan						
	sek.-Butyljodid						
	Methyläthylcarbinjodid						
C_4H_9I	*tert.*-Butyl iodide	$(CH_3)_3CI$	184	98-99	1.370	256	100
	2-Iodo-2-methylpropane						
	β-Iodo-*iso*butane						
	Trimethylcarbiniodide						
	2-Jod-2-methyl propan						
	β-Jod-*iso*butan						
	tert.-Butyljodid						
	Trimethylcarbinjodid						

[1] The maximum dosage tested. [2] The minimum concentration tested. [3] Boiling point—cis., 60; trans., 48. [4] Decomposes.

TABLE 1.—*Empirical formula, synonyms, structural formula, molecular weight, boiling point, specific gravity, concentration of fumigants, and percentage mortality of weevils after exposure for 24 hours*—Continued

Empirical formula	Compound with synonyms	Structural formula	Molecular weight	Boiling point at 760 mm.	Specific gravity 20°/4°	Minimum lethal dosage of fumigant	Weevils killed after exposure for 24 hours
				° *C.*		*Mg. per liter*	*Per cent*
$C_5H_{11}I$	*Iso*amyl iodide 4-Iodo-2-methylbutane 4-Jod-2-Methylbutan *Iso*amyljodid	$(CH_3)_2CHCH_2CH_2I$	198.02	148.0	1.510	151	100
C_3H_5I	Allyl iodide 3-Iodopropylene 3-Iodopropene γ-Iodopropylene 3-Jod-propen-(1) γ-Jod-propylen Allyljodid	$CH_2{=}CHCH_2I$	167.97	103.1	1.848	[3] 37	100
CH_4O	Methyl alcohol Methanol Carbinol Wood alcohol Wood spirit Wood naphtha Methyl hydroxide Methyl hydrate Columbian spirits Columnian spirits Methylalkohol Holzgeist	CH_3OH	32.031	64.5	.792	[1] 396	0
C_2H_6O	Ethyl alcohol Ethanol Grain alcohol Fermentation alcohol Cologne spirit Spirits of wine Äthanol Äthylalkohol Weingeist	CH_3CH_2OH	46.046	78.5	.789	[1] 790	40
C_3H_8O	*n*-Propyl alcohol 1-Propanol Ethyl carbinol Propyl alcohol Propanol-(1)	$CH_3CH_2CH_2OH$	60.062	97.8	.804	[1] 402	60

	α-Oxy-propan Äthyl-carbinol *prim.*-Propylalkohol *n*-Propylalkohol						
C_3H_8O	*Iso*propyl alcohol 2-Propanol Dimethyl carbinol *Iso*propanol Propanol-(2) β-Oxy-propan Dimethyl carbinol *sek.*-Propylalkohol *Iso*propylalkohol	$CH_3CHOHCH_3$	60.062	82.3	.786	220	100
$C_4H_{10}O$	*n*-Butyl alcohol 1-Butanol Propyl carbinol Butanol-(1) α-Oxy-butan Propyl-carbinol *prim.*-Normalbutylalkohol *n*-Butylalkohol	$CH_3CH_2CH_2CH_2OH$	74.077	117.7	.810	[1]405	0
$C_4H_{10}O$	*Iso*butyl alcohol 2-Methyl-1-propanol *Iso*propylcarbinol 2-Methyl-propanol-(1) α-Oxy-β-methyl-propan *Iso*propyl-carb nol *prim.*-*Iso*butylalkohol *Iso*butylalkohol	$(CH_3)_2CHCH_2OH$	74.077	107.3	.802	160	100
$C_4H_{10}O$	*sec.*-Butyl alcohol 2-Butanol Methylethylcarbinol Butylene hydrate Butanol-(2) β-Oxy-butan Methyl-äthyl-carbinol *sek.*-Normalbutylalkohol *sek.*-Butylalkohol	$CH_3CH(OH)CH_2CH_3$	74.077	99.5	.808	162	100
$C_4H_{10}O$	*tert.*-Butyl alcohol 2-Methyl-2-propanol Trimethylcarbinol Dimethyl ethanol 2-Methyl-propanol-(2) β-Oxy-β-methyl-propan *tert.*-*Iso*butylalkohol *tert.*-Butylalkohol	$(CH_3)_3COH$	74.077	82.8	.789	79	100

[1] The maximum dosage tested.

The minimum concentration tested.

TABLE 1.—*Empirical formula, synonyms, structural formula, molecular weight, boiling point, specific gravity, concentration of fumigants, and percentage mortality of weevils after exposure for 24 hours*—Continued

Empirical formula	Compound with synonyms	Structural formula	Molecular weight	Boiling point at 760 mm.	Specific gravity 20°/4°	Minimum lethal dosage of fumigant	Weevils killed after exposure for 24 hours
				° C.		*Mg. per liter*	*Per cent*
$C_5H_{12}O$	*n*-Amyl alcohol 1-Pentanol Butyl carbinol Pentanol-(1) α-Oxy-pentan Butyl-carbinol *prim.*-Normalamylalkohol *n*-Amylalkohol	$CH_3(CH_2)_3CH_2OH$	88.092	137.9	0.817	[1] 409	0
$C_5H_{12}O$	*Iso*amyl alcohol 2-Methyl-4-butanol *Iso*butyl carbinol Fermentation amyl alcohol Fusel oil Grain oil Potato spirit 2-Methyl-butanol-(4) *prim.*-*Iso*amylalkohol *Iso*amylalkohol	$(CH_3)_2CHCH_2CH_2OH$	88.092	130.5	.812	195	100
$C_5H_{12}O$	*sec.*-Amyl alcohol 2-Pentanol Methylpropyl carbinol Pentanol-(2) β-Oxy-pentan Methyl-propyl-carbinol *sek.*-Normalamylalkohol	$CH_3CH(OH)CH_2CH_2CH_3$	88.092	119.5	.809	194	100
$C_5H_{12}O$	Diethyl carbinol 3-Pentanol Pentanol-(3) γ-Oxy-pentan Diäthylcarbinol	$(C_2H_5)_2CHOH$	88.092	115.6	.815	196	100
$C_5H_{12}O$	*tert.*-Amyl alcohol 2-Methyl-2-butanol Dimethylethyl carbinol Amylene hydrate 2-Methyl-butanol-(2) Dimethyl-äthyl-carbinol *tert.*-Amylalkohol Amylenhydrat	$(CH_2)_2C(OH)CH_2CH_3$	88.092	101.8	.809	65	100

$C_8H_{12}O$	*sec.*-Butyl carbinol 2-Methyl-1-butanol Methylethylcarbincarbinol Inactive amyl alcohol Amyl alcohol, active Amyl hydrate 2-Methyl-butanol-(1) Sekundärbutylcarbinol Methyläthylcarbincarbinol d-Amyl alcohol	$CH_3CH_2CH(CH_3)CH_2OH$	88.092	128	.816	163	100
$C_6H_{14}O$	*n*-Hexyl alcohol 1-Hexanol Pentyl carbinol Hexanol-(1) α-Oxy-hexan Pentylcarbinol *prim.*-*n*-Hexylalkohol	$CH_3(CH_2)_4CH_2OH$	102.11	155.8	.820	[1] 410	0
$C_6H_{14}O$	Methylbutyl carbinol 2-Hexanol Hexanol-(2) β-Oxy-hexan *sec*-*n*-Hexyl alcohol	$CH_3CH(OH)(CH_2)_3CH_3$	102.11	131.9	.803	64	100
$C_6H_{14}O$	Dimethyl *n*-propyl carbinol 2-Methyl-2-pentanol β-Oxy-β-methyl pentane 2-Methyl-pentanol-(2) β-Oxy-β-methyl-pentan Dimethylpropylcarbinol	$(CH_3)_2C(OH)CH_2CH_2CH_3$	102.11	122	.823	66	100
$C_7H_{16}O$	*n*-Heptyl alcohol 1-Heptanol Heptylic alcohol Heptanol-(1) α-Oxy-heptan *prim.*-*n*-Heptylalkohol	$CH_3(CH_2)_5CH_2OH$	116.12	175.8	.817	[1] 409	0
$C_7H_{16}O$	Di-*n*-propyl carbinol 4-Heptanol δ-Oxy-heptane Heptanol-(4) δ-Oxy-heptan Dipropyl-carbinol	$(CH_3CH_2CH_2)_2CHOH$	116.12	155.4	.820	[1] 410	30
$C_7H_{16}O$	Triethyl carbinol 3-Ethyl-3-pentanol 3-Äthyl-pentanol-(3) γ-Oxy-γ-äthyl-pentan Triethyl-carbinol	$(CH_3CH_2)_3COH$	116.12	142	.840	134	100
$C_8H_{18}O$	*n*-Octyl alcohol 1-Octanol α-Oxy-octane Octanol-(1) α-Oxy-octan *prim.*-*n*-Octylalkohol	$CH_3(CH_2)_6CH_2OH$	130.14	194	.827	[1] 414	0

[1] The maximum dosage tested.

TABLE 1.—*Empirical formula, synonyms, structural formula, molecular weight, boiling point, specific gravity, concentration of fumigants, and percentage mortality of weevils after exposure for 24 hours*—Continued

Empirical formula	Compound with synonyms	Structural formula	Molecular weight	Boiling point at 760 mm.	Specific gravity 20°/4°	Minimum lethal dosage of fumigant	Weevils killed after exposure for 24 hours
				° C.		Mg. per liter	Per cent
$C_8H_{18}O$	dl-*sec.*-Octyl alcohol 2-Octanol Methyl *n*-hexyl carbinol β-Oxy-octane Capryl alcohol Caprylic alcohol *Sec.*-octylic alcohol Octoic alcohol Octanol-(2) β-Oxy-octan Methyl-hexyl-carbinol *sek.*-*n*-Octylalkohol Caprylalkohol	$CH_3CH(OH)CH_2CH_2CH_2CH_2CH_3$	130. 14	178. 5	0. 819	164	100
$C_9H_{20}O$	*n*-Nonyl alcohol 1-Nonanol α-Oxy-nonane Nonanol-(1) α-Oxy-nonan *prim.*-*n*-Nonylalkohol	$CH_3(CH_2)_7CH_2OH$	144. 15	215	. 828	[1] 414	0
C_3H_6O	Allyl alcohol 1-Propene-3-ol Vinyl carbinol Propen-(1)-ol-(3) γ-Oxy-propylen Allylalkohol	$CH_2{=}CHCH_2OH$	58. 046	97. 0	. 855	171	100
C_2H_5BrO	Ethylene bromohydrin 2-Bromoethyl alcohol 2-Brom-äthanol-(1) Glykolbromhydrin β-Brom-äthylalkohol	CH_2BrCH_2OH	124. 955	150. 3	1. 685	337	100
C_2H_5ClO	Ethylene chlorohydrin 2-Chloroethyl alcohol 2-Chlor-äthanol-(1) β-Chlor-α-oxy-äthan β-Chlor-äthylalkohol Glykolchlorhydrin Äthylenchlorhydrin	CH_2ClCH_2OH	80. 497	128. 8	1. 213	242	100

C_3H_7ClO	Propylene chlorohydrin	$CH_3CHClCH_2OH$	94. 512	134	1. 103	89	100
	2-Chloropropyl alcohol						
	2-Chlor-propanol-(1)						
	β-Chlor-α-oxy-propan						
	β-Chlor-propylalkohol						
	prim.-Propylenchlorhydrin						
C_3H_7ClO	Trimethylene chlorohydrin	$CH_2ClCH_2CH_2OH$	94. 512	160–162	1. 132	[1]566	0
	3-Chlor-propanol-(1)						
	γ-Chlor-α-oxy-propan						
	γ-Chlor-propylalkohol						
C_3H_5ClO	Epichlorohydrin	CH_2Cl CH >O CH_2	92. 497	117	1. 184	[2]24	100
	α-Epichlorohydrin						
	Chlor-methyl-2-äthylen-oxyd						
$C_4H_7Cl_3O$	1, 1, 1-Trichloro-*tert.*-butyl alcohol	$(CH_3)_2C(OH)CCl_3$	177. 43	166. 4	----	[1]500	20
	1. 1. 1-Trichlor-2-methyl-propanol-(2)						
	α-α-α-Trichlor-β-oxy-methylpropan						
	Acetonchloroform						
	Chloretone						
	Acetone chloroform						
	tert.-Trichlorobutyl alcohol						
$C_4H_{11}NO$	β-Dimethylamine ethyl alcohol	$CH_2(CH_3)_2NCH_2OH$	----	135	. 8866	[1]443	0
	Dimethyl-(β-oxy-äthyl)amin						
$C_4H_{10}O$	Diethyl ether	$C_2H_5OC_2H_5$	74. 077	34. 5	. 714	[1]357	10
	Ether						
	Sulphuric ether						
	Ethyl oxide						
	Anaesthesia ether						
	Ethyl ether						
	Aether						
$C_5H_{12}O$	Methyl *n*-butyl ether	$CH_3OC_4H_9$	88. 092	70. 3	. 764	382	100
$C_6H_{14}O$	Ethyl *n*-butyl ether	$C_2H_5OC_4H_9$	102. 11	91. 4	. 752	226	100
$C_6H_{14}O$	Methyl *n*-amyl ether	$CH_3OC_5H_{11}$	102. 11	88. 5	. 754	226	100
$C_6H_{14}O$	*n*-Propyl ether	$C_3H_7OC_3H_7$	102. 11	89	. 747	224	100
	Dipropyl ether						
$C_6H_{14}O$	*Iso*propyl ether	$(CH_3)_2CHOCH(CH_3)_2$	102. 11	68. 7	. 735	353	100
	Di*iso*propyl ether						
$C_8H_{18}O$	*n*-Butyl ether	$C_4H_9OC_4H_9$	130. 14	140. 9	. 769	[1]385	60
$C_{10}H_{22}O$	*n*-Amyl ether	$C_5H_{11}OC_5H_{11}$	158. 17	190	. 774	[1]387	0
$C_{10}H_{22}O$	*Iso*amyl ether	$((CH_3)_2CHCH_2CH_2)_2O$	158. 17	172. 2	. 783	[1]397	0
	Di*iso*amyl ether						
	Amyl oxide						
	Amyl ether						
	Diamyl ether						
	Amylic ether						
$C_5H_{10}O$	Ethyl allyl ether	$C_2H_5OCH_2CH=CH_2$	86. 077	67. 6	. 765	[1]383	90
$C_4H_{10}O_2$	Ethyl ne glycol monoethyl ether	$CH_2OHCH_2OC_2H_5$	90. 077	135. 3	. 935	[1]468	0
	Glycol ethyl ether						

[1] The maximum dosage tested.

[2] The minimum concentration tested.

TABLE 1.—*Empirical formula, synonyms, structural formula, molecular weight, boiling point, specific gravity, concentration of fumigants, and percentage mortality of weevils after exposure for 24 hours*—Continued

Empirical formula	Compound with synonyms	Structural formula	Molecular weight	Boiling point at 760 mm.	Specific gravity 20°/4°	Minimum lethal dosage of fumigant	Weevils killed after exposure for 24 hours
				°C.		*Mg. per liter*	*Per cent*
C_2H_4O	Ethylene oxide α β-Oxido-äthan	CH_2 | >O CH_2	44.031	10.7	0.887	[2] 20	100
C_3H_6O	Propylene oxide α-Propylene oxide Methyl-äthylenoxyd	CH_3CH | >O CH_2		35	.90	54	100
C_2H_5ClO	Chloromethyl ether Chloromethyl methyl ether	CH_2ClOCH_3	80.497	59.5	1.063	[1] 532	0
$C_2H_4Cl_2O$	*sym.*-Dichloromethyl ether Dichloromethyl ether	CH_2ClOCH_2Cl	114.947	106	1.315	658	100
C_4H_9BrO	β-Bromoethyl ethyl ether 2-Bromoethyl ethyl ether	$CH_2BrCH_2OCH_2CH_3$	152.99	128.2	1.370	[2] 27	100
$C_4H_8Cl_2O$	β-β-Dichloroethyl ether 2-Chloroethyl ether	$CH_2ClCH_2OCH_2CH_2Cl$	142.98	178	1.213	[2] 24	100
$C_4H_8Cl_2O$	α-β-Dichloroethyl ether 1, 2-Dichloroethyl ethyl ether α-β-Dichlor-diäthyläther α-β-Dichlor-(α-äthoxy)-äthan Dichloroether Dichloroethyl oxide	$CH_2ClCH_2ClOCH_2CH_3$	142.98	145	1.174	188	100
$C_3H_8O_2$	Methylal Methylene dimethyl ether Formal Methylenedimethyl ester Methylendimethylate	$CH_2(OCH_3)_2$	76.062	44	.862	[1] 431	40
$C_5H_{12}O_2$	Ethylal Methylene diethyl ether	$CH_2(OC_2H_5)_2$	104.09	89	.851	340	100
$C_6H_{14}O_2$	Acetal Ethidene diethyl ether Diethylacetal Ethylidenediethylic ether Diethylaldehyde	$CH_3CH(OC_2H_5)_2$	118.11	102.2	.831	332	100
$C_4H_{10}O_2$	Dimethylacetal Acetaldehyde dimethyl acetal α-α-Dimethoxy-äthan Äthylidendimethyläther Ethylidenedimethyl ester	$CH_3CH(OCH_3)_2$	90.077	64.4	.866	346	100

CH_2O	Formaldehyde Methanal Oxomethan Ameisensäurealdehyd Oxymethylene Formalin Formalith Formic aldehyde	HCHO	30.015	21	----	[1] 200	0
C_2H_4O	Acetaldehyde Äthanal Oxoäthan Essigsäurealdehyd Leichter säuerstoffäther Ethylaldehyde Acetic aldehyde Ethanal Aldehyde	CH_3CHO	44.031	20.2	.781	469	100
C_3H_6O	Propionaldehyde Propanal α-Oxo-propan Propyl aldehyde Propionic aldehyde Propylic aldehyde	CH_3CH_2CHO	58.046	48.8	.807	[1] 404	0
C_4H_8O	*n*-Butyraldehyde Butanal α-Oxo-butan	$CH_3CH_2CH_2CHO$	72.062	75.7	.817	[1] 409	0
C_4H_8O	*Iso*butyraldehyde Methyl propanal α-Oxo-β-methyl-propan *Iso*butyl aldehyde *Iso*butyryl aldehyde	$(CH_3)_2CHCHO$	72.062	61	.794	79	100
$C_5H_{10}O$	*Iso*valeraldehyde 2-Methyl-4-butanal δ-Oxo-β-methyl-butan *Iso*propylacetaldehyde *Iso*valeric aldehyde *Iso*valeral	$(CH_3)_2CHCH_2CHO$	86.077	92.5	.803	[1] 402	90
$C_7H_{14}O$	Heptaldehyde Oenanthol Oenanthic aldehyde Heptanal Heptoic aldehyde Oenanthal α-Oxo-heptan Önanthaldehyd Önanthol	$C_6H_{13}CHO$	114.11	155	.850	[1] 425	0
C_2HCl_3O	Chloral Trichloroacetaldehyde 2, 2, 2-Trichlor-äthanol-(1) Trichloroacetic aldehyde	CCl_3CHO	147.38	98.1	1.512	454	100

[1] The maximum dosage tested.

[2] The minimum concentration tested.

TABLE 1.—*Empirical formula, synonyms, structural formula, molecular weight, boiling point, specific gravity, concentration of fumigants, and percentage mortality of weevils after exposure for 24 hours*—Continued

Empirical formula	Compound with synonyms	Structural formula	Molecular weight	Boiling point at 760 mm.	Specific gravity 20°/4°	Minimum lethal dosage of fumigant	Weevils killed after exposure for 24 hours
				° *C.*		*Mg. per liter*	*Per cent*
C_3H_4O	Acrolein Propenal γ-Oxo-propylen Acrylaldehyde Acrylic aldehyde Acraldehyde	$CH_2=CHCHO$	56.031	52.5	0.841	168	100
$C_6H_{10}O$	α-Methyl-β-ethylacrolein 1-Ethyl-2-methylacrolein 2-Methyl-penten-(2)-al-(1)	$CH_3CH_2CH=C(CH_3)CHO$	98.077	137.3	.858	257	100
C_4H_6O	Crotonaldehyde Buten-(2)-al-(1) α-Oxo-β-butylen β-Methylacrolein	$CH_3CH=CHCHO$	70.046	104	.859	344	100
C_3H_6O	Acetone Dimethyl ketone Propanone β-Oxo-propan Dimethylketal Ketopropane Methylacetyl Pyroacetic ether	CH_3COCH_3	58.046	56.1	.7915	396	100
C_4H_8O	Ethyl methyl ketone Butanone β-Oxo-butan β-Keto-butan Äthyl-acetyl Propionsäure-methylketon Methylethyl ketone	$C_2H_5COCH_3$	72.062	79.6	.805	242	100
$C_5H_{10}O$	Diethyl ketone 3-Pentanone γ-Oxo-pentan *sym.*-Dimethyl-acetone Propion Metacetone Propione Ethyl propionyl	$C_2H_5COC_2H_5$	86.077	101.7	.814	163	100

$C_5H_{10}O$	Methyl *n*-propyl ketone 2-Pentanone β-Oxo-pentan Propyl-acetyl Buttersäure-methylketon Äthyl-aceton	$CH_3COC_3H_7$	86.077	101.7	.812	97	100
$C_6H_{12}O$	Methyl *n*-butyl ketone 2-Hexanone β-Oxo-hexan *n*-Valeriansäure-methylketon	$CH_3COC_4H_9$	100.09	127.2	.830	83	100
$C_6H_{12}O$	Methyl *iso*butyl ketone 2-Methyl-4-pentanone δ-Oxo-β-methyl-pentan *Iso*propylaceton	$CH_3COCH_2CH(CH_3)_2$	100.09	119	.803	64	100
$C_7H_{14}O$	Dipropyl ketone 4-Heptanone δ-Oxo-heptan Di-*n*-propyl ketone Butyron	$C_3H_7COC_3H_7$	114.11	143.5	.821	131	100
$C_7H_{14}O$	Methyl *n*-amyl ketone 2-Heptanone β-Oxo-heptan	$CH_3COC_5H_{11}$	114.11	150	.822	230	100
$C_9H_{18}O$	Di-*n*-butyl ketone 5-Nonanone ε-Oxo-nonan Dibutylketon	$C_4H_9COC_4H_9$	142.14	175	.827	[1] 410	0
$C_{11}H_{22}O$	Di-*n*-amyl ketone 6-Undecanone ζ-Oxo-undecan Capron Diamyl ketone	$C_5H_{11}COC_5H_{11}$	170.17	226.3	.826	[1] 413	0
C_3H_5ClO	Chloroacetone Chloropropanone α-Chlor-β-oxo-propan Acetonylchloride Monochloroacetone Monochlorinated acetone	$CH_2ClCOCH_3$	92.497	121	1.162	116	100
$C_6H_{10}O$	Mesityl oxide 2-Methyl-2-penten-4-one *Iso*propyliden-aceton	$(CH_3)_2{=}C{=}CHCOCH_3$	98.077	135	.863	52	100
$C_4H_6O_2$	Diacetyl Butandion β-γ-Dioxo-butan Dimethyl glyoxal	$CH_3COCOCH_3$	86.046	88	.975	[1] 488	0
$C_5H_8O_2$	Acetylacetone Pentandion-(2.4) β-δ-Dioxo-pentan Diacetylmethan	$CH_3COCH_2COCH_3$	100.062	137	.976	195	100

[1] The maximum dosage tested.

TABLE 1.—*Empirical formula, synonyms, structural formula, molecular weight, boiling point, specific gravity, concentration of fumigants, and percentage mortality of weevils after exposure for 24 hours*—Continued

Empirical formula	Compound with synonyms	Structural formula	Molecular weight	Boiling point at 760 mm.	Specific gravity 20°/4°	Minimum lethal dosage of fumigant	Weevils killed after exposure for 24 hours
				° *C.*		*Mg. per liter*	*Per cent*
CH_2O_2	Formic acid Methansäure Ameisensäure Acidum formicum Acid hydrogen carboxylic	$HCOOH$	46.015	100.5	1.220	[1] 610	0
$C_2H_4O_2$	Acetic acid Äthansäure Methan-carbonsäure Essigsäure Acidum aceticum Acid methanecarboxylic Vinegar acid	CH_3COOH	60.031	118.1	1.049	[1] 525	0
$C_2H_3ClO_2$	Chloroacetic acid Chloräthansäure Chloressigsäure Monochloroacetic acid	$CH_2ClCOOH$	94.481	189.5	1.370	[1] 500	0
$C_3H_6O_2$	Propionic acid Propansäure Äthancarbonsäure Methylessigsäure Methylacetic acid Metactonic acid Ethylcarbonic acid	CH_3CH_2COOH	74.046	141.1	.992	[1] 496	0
$C_4H_8O_2$	*n*-Butyric acid Butansäure Propan α carbonsäure Äthyessigsäure *n*-Buttersäure Buttersäure Propylformic acid Butyric acid	$CH_3CH_2CH_2COOH$	88.062	163.5	.959	[1] 480	0
$C_4H_8O_2$	*Iso*butyric acid Methylpropansäure Propan-β-carbonsäure Dimethylessigsäure *Iso*buttersäure	$(CH_3)_2CHCOOH$	88.062	154.4	.949	[1] 475	0

$C_5H_{10}O_2$	*n*-Valeric acid Pentansäure Butan-α-carbonsäure Propylessigsäure *n*-Valeriansäure Propylacetic acid Normal valeric acid	$CH_3CH_2CH_2CH_2COOH$	102.08	187	.942	[1] 471	0
$C_5H_{10}O_2$	*Iso*valeric acid 2-Methyl-butansäure-(4) β-Methyl-propau-α-carbonsäure β-Methyl-*n*-buttersäure *Iso*propylessigsäure *Iso*butylameisensäure *Iso*valeriansäure Pentoic acid, primary Valerianic acid Valeric acid, anhydrous. Valeric acid, monohydrate *Iso*butylcarbonyl	$(CH_3)_2CHCH_2COOH$	102.08	176.7	.937	[1] 469	0
$C_5H_{10}O_2$	dl-Methylethylacetic acid 2-Methyl-butansäure-(1) Butan-β-carbonsäure α-Methyl-buttersäure Methyl-äthylessigsäure	$CH_3CH_2CH(CH_3)COOH$	102.08	174	.941	[1] 471	0
$C_2H_2Br_2O$	Bromoacetyl bromide Bromäthanoylbromid Bromacetylbromid	$CH_2BrCOBr$	201.85	150	2.317	[1] 1,159	0
$C_2H_2Cl_2O$	Chloroacetyl chloride Chloräthanoylchlorid Chloracetylchlorid	$CH_2ClCOCl$	112.931	105	1.495	[1] 748	0
C_2HCl_3O	Dichloroacetyl chloride Dichloräthanoylchlorid Dichloracetylchlorid	$CHCl_2COCl$	147.38	108	1.56	[1] 780	0
C_2Cl_4O	Trichloroacetyl chloride Trichloräthanoylchlorid Trichloracetylchlorid	CCl_3COCl	181.832	118	1.629	[1] 815	0
C_3H_5ClO	Propionyl chloride Propanoylchlorid Propionylchlorid	C_2H_5COCl	92.497	80	1.065	[1] 533	0
C_4H_7ClO	*n*-Butyryl chloride Butyryl chloride Butanoylchlorid Buttersäurechlorid Butyrylchlorid	C_3H_7COCl	106.51	102	1.028	[1] 514	0
C_5H_9ClO	*n*-Valeryl chloride Pentanoylchlorid *n*-Valeriansäurechlorid *n*-Valerylchlorid	C_4H_9COCl	120.53	128	1.016	[1] 508	0
C_5H_9ClO	*Iso*valeryl chloride 2-Methyl-butanoylchlorid-(4) *Iso*valeriansäurechlorid *Iso*valerylchlorid	$(CH_3)_2CHCH_2COCl$	120.53	113	.9887	[1] 495	0

[1] The maximum dosage tested.

TABLE 1.—*Empirical formula, synonyms, structural formula, molecular weight, boiling point, specific gravity, concentration of fumigants, and percentage mortality of weevils after exposure for 24 hours*—Continued

Empirical formula	Compound with synonyms	Structural formula	Molecular weight	Boiling point at 760 mm.	Specific gravity 20°/4°	Minimum lethal dosage of fumigant	Weevils killed after exposure for 24 hours
				° C.		*Mg. per liter*	*Per cent*
$C_2Cl_2O_2$	Oxalyl chloride Oxalsäuredichlorid Oxalylchlorid	$(COCl)_2$	126.916	64	1.488	[1] 744	30
$C_2H_4O_2$	Methyl formate Ameisensäuremethylester Methylformiat	$HCOOCH_3$	60.031	31.8	.975	39	100
$C_3H_6O_2$	Ethyl formate Ameisensäureäthylester Äthylformiat Formic ether	$HCOOC_2H_5$	74.046	54.3	.906	72	100
$C_4H_8O_2$	*n*-Propyl formate Propylformiat	$HCOOC_3H_7$	88.062	81.3	.901	72	100
$C_4H_8O_2$	*Iso*propyl formate *Iso*propylformiat	$HCOOCH(CH_3)_2$	88.062	71.3	.883	53	100
$C_5H_{10}O_2$	*n*-Butyl formate Butylformiat	$HCOOC_4H_9$	102.08	106.8	.911	109	100
$C_5H_{10}O_2$	*Iso*butyl formate *Iso*butylformiat	$HCOOCH_2CH(CH_3)_2$	102.08	98.2	.875	35	100
$C_7H_{16}O_3$	Ethyl orthoformate Triäthylester der orthoameisensäure Triäthylorthoformiat Orthoameisensäureäthylester Triäthoxy-methan	$HC(OC_2H_5)_3$	148.12	145.9	.897	90	100
$C_6H_{12}O_2$	*Iso*amyl formate Ameisensäure*iso*amylester *Iso*amylformiat Amyl formate	$HCOOCH_2CH_2CH(CH_3)_2$	116.09	123.5	.871	70	100
$C_4H_6O_2$	Allyl formate Ameisensäureallylester Allylformiat	$HCOOCH_2CH{=}CH_2$	86.046	83	.948	38	100
$C_2H_3ClO_2$	Methyl chloroformate Methyl chlorocarbonate Kohlensäuremethylesterchlorid Chlorameisensäuremethylester Methylchlorformiat	$ClCOOCH_3$	94.481	71.4	1.236	198	100
$C_3H_5ClO_2$	Ethyl chloroformate Ethyl chlorocarbonate	$ClCOOC_2H_5$	108.497	95	1.139	251	100

$C_3H_4Cl_2O$	Kohlensäureäthylesterchlorid Chlorameisensäureäthylester Carbäthoxychlorid Chlorkohlensäureäthylester β-Chloroethyl chloroformate Chlorameisensäure-(β-chlor-äthyl)-ester	$ClCOOCH_2CH_2Cl$		150-160	1.2	180	100
$C_4H_7ClO_2$	*n*-Propyl chloroformate *n*-Propylchlorocarbonate Chlorameisensäurepropylester	$ClCOOCH_2CH_2CH_3$	122.51	116	1.083	[1]542	20
$C_4H_6Cl_2O_2$	γ-Chloropropyl chloroformate γ-Chloropropyl chlorocarbonate	$ClCOOCH_2CH_2CH_2Cl$	156.96	58-60 (8 mm.)	1.2	[1]600	10
$C_4H_7ClO_2$	*Iso*propyl chloroformate *Iso*propyl chlorocarbonate Chlorameisensäure*iso*propylester	$ClCOOCH(CH_3)_2$	122.512	53-54 (160 mm.)	1.08	[1]540	70
$C_5H_9ClO_2$	*n*-Butyl chloroformate *n*-Butyl chlorocarbonate	$ClCOOCH_2CH_2CH_2CH_3$	136.53	138.9	1.078	[1]539	0
$C_5H_9ClO_2$	*Iso*butyl chloroformate *Iso*butyl chlorocarbonate Chlorameisensäure*iso*butylester	$ClCOOCH_2CH(CH_3)_2$	136.53	130	1.040	[1]520	20
$C_6H_{11}ClO_2$	*Iso*amyl chloroformate *Iso*amyl chlorocarbonate Chlorameisensäure*iso*amylester	$ClCOOCH_2CH_2CH(CH_3)_2$	150.51	156	1.024	[1]512	0
$C_3H_6O_2$	Methyl acetate Essigsäuremethylester Methylacetat	CH_3COOCH_3	74.046	57.1	.933	187	100
$C_4H_8O_2$	Ethyl acetate Acetic ether Essigäther Äthylacetat Essigsäureäthylester Aether aceticus Vinegar naphtha	$CH_3COOCH_2CH_3$	88.062	77.1	.899	180	100
$C_5H_{10}O_2$	*n*-Propyl acetate *n*-Propyl-acetat	$CH_3COOCH_2CH_2CH_3$	102.08	101.6	.887	89	100
$C_5H_{10}O_2$	*Iso*propyl acetate *Iso*propylacetat	$CH_2COOCH(CH_3)_2$	102.08	89	.877	110	100
$C_6H_{12}O_2$	*n*-Butyl acetate *n*-Butyl-acetat	$CH_3COOCH_2CH_2CH_2CH_3$	116.09	126.5	.882	212	100
$C_6H_{12}O_2$	*Iso*butyl acetate *Iso*butylacetat	$CH_3COOCH_2CH(CH_3)_2$	116.09	118.3	.871	87	100
$C_6H_{12}O_2$	*sec.*-Butyl acetate *sek.* Butyl-acetat	$CH_3COOCH(CH_3)CH_2CH_3$	116.09	112.2	.870	122	100
$C_7H_{14}O_2$	*Iso*amyl acetate *Iso*amyl-acetat Amyl acetate Banana oil Amylacetic ether	$CH_3COOC_5H_{11}$	130.11	142.5	.875	175	100
$C_9H_{18}O_2$	*n*-Heptyl acetate *n*-Heptyl-acetat	$CH_3COOC_7H_{15}$	158.14	191.5	.874	[1]437	0

[1] The maximum dosage tested.

TABLE 1.—*Empirical formula, synonyms, structural formula, molecular weight, boiling point, specific gravity, concentration of fumigants, and percentage mortality of weevils after exposure for 24 hours*—Continued

Empirical formula	Compound with synonyms	Structural formula	Molecular weight	Boiling point at 760 mm.	Specific gravity 20°/4°	Minimum lethal dosage of fumigant	Weevils killed after exposure for 24 hours
				°C.		*Mg. per liter*	*Per cent*
$C_{10}H_{20}O_2$	*sec.*-Octyl acetate Methylhexylcarbin-acetat Capryl-acetat	$CH_3COOCH(CH_3)(CH_2)_5CH_3$	172. 15	193	0. 87	[1] 435	0
$C_3H_5BrO_2$	Bromomethyl acetate Essigsäure-(brom-methyl)-ester	CH_3COOCH_2Br	152. 95	130–133	1. 5	[1] 750	60
$C_4H_7BrO_2$	2-Bromoethyl acetate β-Bromo ethyl acetate β-Brom-äthyl-acetat	$CH_3COOCH_2CH_2Br$	166. 971	70 (27 mm.)	1. 514	[2] 30	100
$C_4H_7ClO_2$	2-Chloroethyl acetate β-Chloro ethyl acetate β-Chlor-athyl-acetat	$CH_3COOCH_2CH_2Cl$	122. 51	145	1. 178	47	100
$C_5H_9BrO_2$	3-Bromopropyl acetate γ-Bromo propyl acetate	$CH_3COOCH_2CH_2CH_2Br$	180. 987	------	1. 2	[1] 600	0
$C_3H_5BrO_2$	Methyl bromoacetate	$CH_2BrCOOCH_3$	152. 95		1. 5	[2] 30	100
$C_4H_7BrO_2$	Ethyl bromoacetate Bromessigester	$CH_2BrCOOCH_2CH_3$	166. 97	159	1. 514	[2] 30	100
$C_3H_5ClO_2$	Methyl chloroacetate Methyl-chloracetat	$CH_2ClCOOCH_3$	108. 497	130	1. 22	73	100
$C_4H_7ClO_2$	Ethyl chloroacetate Äthyl-chloracetat	$CH_2ClCOOCH_2CH_3$	122. 51	145. 5	1. 159	93	100
$C_5H_9ClO_2$	*Iso*propyl chloroacetate *Iso*propylchloracetat	$CH_2ClCOOCH(CH_3)_2$	136. 526	149. 5	1. 09	[2] 22	100
$C_6H_{11}ClO_2$	*sec.*-Butyl chloroacetate *sek.*-Butyl-chloracetat	$CH_2ClCOOCH(CH_3)CH_2CH_3$	150. 534	167. 5	1. 06	66	100
$C_6H_{11}ClO_2$	*n*-Butyl chloroacetate	$CH_2ClCOOCH_2CH_2CH_2CH_3$	150. 534	175	1. 081	216	100
$C_4H_6Cl_2O_2$	Ethyl dichloroacetate	$CHCl_2COOCH_2CH_3$	156. 96	158. 2	1. 282	256	100
$C_4H_5Cl_3O_2$	Ethyl trichloroacetate	$CCl_3COOCH_2CH_3$	191. 41	168	1. 383	692	100
$C_5H_9BrO_2$	Ethyl 1-bromopropionate Ethyl α-bromopropionate dl-α-Brom-propionsäureäthylester 2-Brom-propansäure-(1)-äthylester	$CH_3CHBrCOOCH_2CH_3$	180. 99	160	1. 393	84	100
$C_5H_9BrO_2$	Ethyl 2-bromopropionate Ethyl β-bromopropionate 3-Brom-propansäure-(1)-äthylester β-Brom-propionsäureäthylester	$CH_2BrCH_2COOCH_2CH_3$	180. 99	135–136 (50 mm.)	1. 4	[1] 700	80
$C_5H_9ClO_2$	Ethyl 2-chloropropionate Ethyl β-chloropropionate	$CH_2ClCH_2COOCH_2CH_3$	136. 54	162. 5	1. 114	[1] 557	90

	3-Chlor-propansäure-(1)-äthylester β-Chlor-propionsäureäthylester						
$C_5H_7NO_2$	Ethyl cyanoacetate Malonsäure-äthylester-nitril Cyanessigsäure-äthylester Cyanessigester	$CH_2(CN)COOC_2H_5$	113.06	206	1.063	[1]532	**0**
$C_4H_8O_2$	Methyl propionate Methylpropionat	$CH_3CH_2COOCH_3$	88.062	79.9	.917	183	100
$C_5H_{10}O_2$	Ethyl propionate Äthylpropionat	$CH_3CH_2COOCH_2CH_3$	102.08	99.1	.891	125	100
$C_6H_{12}O_2$	*n*-Propyl propionate Propylpropionat	$CH_3CH_2COOCH_2CH_2CH_3$	116.09	123.4	.883	124	100
$C_7H_{14}O_2$	*n*-Butyl propionate Butylpropionat	$CH_3CH_2COOC_4H_9$	130.11	146	.883	[1]442	60
$C_7H_{14}O_2$	*Iso*butyl propionate *Iso*butylpropionat	$CH_3CH_2COOCH_2CH(CH_3)_2$	130.11	136.8	.869	174	100
$C_8H_{16}O_2$	*Iso*amyl propionate *Iso*amylpropionat	$CH_3CH_2COOC_5H_{11}$	144.12	160.2	.870	435	100
$C_4H_8O_3$	Methyl lactate α-Oxo-propionsäuremethylester Milchsäuremethylester	$CH_3CH(OH)COOCH_3$	104.062	144.8	1.08	[1]540	0
$C_5H_{10}O_3$	Ethyl lactate α-Oxo-propionsäure-äthylester Milchsäureäthylester	$CH_3CH(OH)COOC_2H_5$	118.08	154	1.031	[1]516	**0**
$C_5H_{10}O_2$	Methyl *n*-butyrate Methylbutyrat	$CH_3CH_2CH_2COOCH_3$	102.08	102.3	.898	180	100
$C_6H_{12}O_2$	Ethyl *n*-butyrate Äthylbutyrat Butyric ether	$CH_3CH_2CH_2COOCH_2CH_3$	116.09	121.3	.870	264	100
$C_7H_{14}O_2$	*n*-Propyl *n*-butyrate Propyl *n*-butyrate Propylbutyrat	$CH_3CH_2CH_2COOC_3H_7$	130.11	143	.879	[1]440	40
$C_8H_{16}O_2$	*n*-Butyl *n*-butyrate Butyl *n*-butyrate Butylbutyrate	$CH_3CH_2CH_2COOC_4H_9$	144.12	166.4	.872	[1]436	0
$C_8H_{16}O_2$	*Iso*butyl *n*-butyrate *Iso*butylbutyrat	$C_3H_7COOCH_2CH(CH_3)_2$	144.12	156.9	.866	[1]133	**0**
$C_9H_{18}O_2$	*Iso*amyl *n*-butyrate *Iso*amylbutyrat	$C_3H_7COOC_5H_{11}$	158.11	178.6	.882	[1]441	10
$C_6H_{12}O_2$	Ethyl *iso*butyrate Äthyl*iso*butyrat *Iso*butyric ether	$(CH_3)_2CHCH_2COOC_2H_5$	116.09	111.7	.871	87	100
$C_8H_{16}O_2$	*Iso*butyl *iso*butyrate *Iso*butyl*iso*butyrat	$(CH_3)_2CHCH_2COOCH_2CH(CH_3)_2$	144.12	148.7	.875	263	100
$C_6H_{12}O_2$	Methyl *n*-valerate Methylvalerianat	$C_4H_9CO_2CH_3$	116.09	127.3	.910	255	100
$C_7H_{14}O_2$	Ethyl *n*-valerate Äthylvalerianat Ethyl valerianate Ethyl valeriate	$C_4H_9CO_2CH_2CH_3$	130.11	145.5	.877	[1]439	70

[1] The maximum dosage tested.

[2] The minimum concentration tested.

TABLE 1.—*Empirical formula, synonyms, structural formula, molecular weight, boiling point, specific gravity, concentration of fumigants, and percentage mortality of weevils after exposure for 24 hours*—Continued

Empirical formula	Compound with synonyms	Structural formula	Molecular weight	Boiling point at 760 mm.	Specific gravity 20°/4°	Minimum lethal dosage of fumigant	Weevils killed after exposure for 24 hours
				° C.		Mg. per liter	Per cent
$C_9H_{18}O_2$	*n*-Butyl *n*-valerate	$C_4H_9CO_2C_4H_9$	158.14	185.8	0.885	[1] 443	0
	Butylvalerianat						
$C_7H_{14}O_2$	Ethyl *iso*valerate	$(CH_3)_2CHCH_2CO_2C_2H_5$	130.11	135	.866	173	100
	Äthyl *iso*valerianat						
$C_8H_{16}O_2$	*n*-Propyl *iso*valerate	$(CH_3)_2CHCH_2CO_2C_3H_7$	114.12	155.9	.863	[1] 432	0
$C_9H_{18}O_2$	*Iso*butyl *iso*valerate	$(CH_3)_2CHCH_2CO_2CH_2CH(CH_3)_2$	158.14	168.5	.871	[1] 427	0
$C_{10}H_{20}O_2$	*Iso*amyl *iso*valerate	$(CH_3)_2CHCH_2CO_2CH_2CH_2CH(CH_3)_2$	172.15	194	.870	[1] 435	0
$C_7H_{14}O_2$	Methyl *n*-caproate	$C_5H_{11}COOCH_3$	130.14	149.5	.904	[1] 452	0
	Hexansäuremethylester						
	Pentan-α-carbonsäuremethylester						
	Normalcapronsäuremethylester						
	Methylcapronat						
$C_8H_{16}O_2$	Ethyl *n*-caproate	$C_5H_{11}COOC_2H_5$	144.12	166.6	.875	[1] 438	0
	Äthylcapronat						
	Ethyl caproate						
	Ethyl capronate						
	Caproic ether						
	Capronic ether						
$C_8H_{16}O_2$	Methyl *n*-heptylate	$C_6H_{13}COOCH_3$	144.12	172.1	.881	[1] 441	0
	Önansäuremethylester						
	Heptansäuremethylester						
	Hexan-α-carbonsäuremethylester						
$C_9H_{18}O_2$	Ethyl *n*-heptylate	$C_6H_{13}COOC_2H_5$	158.14	187.1	.872	[1] 436	0
	Oenanthic ether						
	Cognac oil						
	Oenanthylic ether						
	Önansäureäthylester						
	Heptansäureäthylester						
	Hexan-α-carbonsäureäthylester						
$C_9H_{18}O_2$	Methyl caprylate	$C_7H_{15}COOCH_3$	158.14	192.9	.887	[1] 441	0
	Octansäuremethylester						
	Heptan-α-carbonsäuremethylester						
	n-Caprylsäuremethylester						
	n-Octylsäuremethylester						
$C_4H_6O_4$	Dimethyl oxalate	$(COOCH_3)_2$	118.046	163.3	1.120	[1] 500	0
	Methyl oxalate						

	Oxalsäuredimethylester Dimethyloxalat						
$C_6H_{10}O_4$	Diethyl oxalate Ethyl oxalate Oxalsäurediäthylester Diäthyloxalat	$(COOC_2H_5)_2$	146.08	186.1	1.080	[1] 540	
$C_{12}H_{22}O_4$	Di*iso*amyl oxalate *Iso*amyl oxalate Di*iso*amyloxalat	$(CH_3)_2CHCH_2CH_2O_2CCO_2CH_2CH_2CH(CH_3)_2$	230.17	265	.968	[1] 484	0
$C_3H_6O_3$	Dimethyl carbonate Methyl carbonate Dimethylcarbonat	$CO(OCH_3)_2$	90.046	89.7	1.069	[1] 535	90
$C_5H_{10}O_3$	Diethyl carbonate Ethyl carbonate Carbonic ether Diethylcarbonic ether Diäthylcarbonat	$CO(OC_2H_5)_2$	118.08	125.8	.979	196	100
$C_7H_{14}O_3$	Di-*n*-propyl carbonate Dipropylcarbonat	$CO(OC_3H_7)_2$	146.11	168.2	.968	[1] 484	0
$C_9H_{18}O_3$	Di-*n*-butyl carbonate Dibutylcarbonat	$CO(OC_4H_9)_2$	174.14	207.7	.924	[1] 462	0
$C_9H_{18}O_3$	Di*iso*butyl carbonate Di*iso*butylcarbonat	$CO((CH_3)_2CHCH_2)_2$	174.14	190.3	.919	[1] 460	10
$C_{11}H_{22}O_3$	Di*iso*amyl carbonate Di*iso*amylcarbonat	$CO(OC_5H_{11})_2$	202.17	228.7	.912	[1] 456	0
$C_6H_{10}O_4$	Ethylidene diacetate Diacetat des Acetaldehydhydrats Äthylidenglykol-diacetat Äthylidendiacetat	$CH_3CH(CH_3COO)_2$	146.08	169	.852	[1] 426	0
$C_2H_{12}O_2$	Ethyl β-β dimethyl acrylate 2-Methyl-buten-(2)-säure-(4)-äthylester β-Methyl-α-propylen-α-carbonsäure-äthylester β-β-Dimethyl-acrylsäure-äthylester	$(CH_3)_2C{=}CHCOOC_2H_5$	128.09	155	.922	203	100
$C_6H_{10}O_3$	Ethyl acetoacetate β-Keto-buttersäure-äthylester Acetessigsäureäthylester Acetessigester Diacetic ether	$CH_3COCH_2COOC_2H_5$	130.08	180	1.025	[1] 513	0
CH_5N	Methylamine (33 per cent in water) Aminomethan Carbinamin Methylamin	CH_3NH_2	31.047	−6.5		[1] 167	0
C_2H_7N	Ethylamine Aminoäthan Äthylamin	$CH_3CH_2NH_2$	45.062	16.6	.689	[1] 345	0
C_3H_9N	*n*-Propylamine 1-Amino-propan α-Amino-propan Propylamin	$CH_3CH_2CH_2NH_2$	59.077	48.7	.719	[1] 360	0

[1] The maximum dosage tested.

TABLE 1.—*Empirical formula, synonyms, structural formula, molecular weight, boiling point, specific gravity, concentration of fumigants, and percentage mortality of weevils after exposure for 24 hours*—Continued

Empirical formula	Compound with synonyms	Structural formula	Molecular weight	Boiling point at 760 mm.	Specific gravity 20°/4°	Minimum lethal dosage of fumigant	Weevils killed after exposure for 24 hours
				° *C.*		*Mg. per liter*	*Per cent*
C_3H_9N	*Iso*propylamine 2-Amino-propan β-Amino-propan *Iso*propylamin	$(CH_2)_2CHNH_2$	59.077	34	0.694	278	100
$C_4H_{11}N$	*n*-Butylamine 1-Amino-butan α-Amino-butan *prim.*-Normalbutylamin Butylamin	$CH_3CH_2CH_2CH_2NH_2$	73.093	76	.740	[1]370	0
$C_4H_{11}N$	*Iso*butylamine 1-Amino-2-methyl-propan α-Amino-β-methyl-propan *Iso*butylamin	$(CH_3)_2CHCH_2NH_2$	73.093	68	.736	294	100
$C_4H_{11}N$	*sec.*-Butylamine 2-Amino-butan β-Amino-butan Methylethylcarbin-amin *sek.*-Normalbutylamin *sek.*-Butylamin	$CH_2CHNH_2CH_2CH_3$	73.093	63	.718	215	100
$C_5H_{13}N$	*n*-Amylamine 1-Amino-pentan α-Amino-pentan *prim.*-Normalamylamin *n*-Amylamin	$CH_3CH_2CH_2CH_2CH_2NH_2$	87.108	104	.766	[1]383	0
$C_5H_{13}N$	*Iso*amylamine 4-Amino-2-methyl-butan δ-Amino-β-methyl-butan *Iso*butylcarbinamin *Iso*amylamin	$CH_3CH(CH_3)CH_2CH_2NH_2$	87.108	95	.751	300	100
C_3H_7N	Allylamine 3-Amino-propen-(1) γ-Amino-α-propylen Allylamin	$CH_2{=}CHCH_2NH_2$	57.062	53.2	.761	[1]381	50
C_2H_7N	Dimethylamine (33 per cent in water) Dimethylamin	$(CH_3)_2NH$	45.062	7.4	.680	[1]340	0

$C_4H_{11}N$	Diethylamine Diäthylamin	$(C_2H_5)_2NH$	73.093	56.0	.711	142	100
$C_6H_{15}N$	Di-*n*-propylamine Dipropylamin	$(C_3H_7)_2NH$	101.12	110.7	.738	221	100
$C_6H_{15}N$	Di*iso*propylamine Di*iso*propylamin	$\left(\begin{matrix}CH_3\\CH_3\end{matrix}\right\}CH\Big)_2NH$	101.12	84	.722	72	100
$C_8H_{19}N$	Di-*n*-butylamine Dibutylamin	$(C_4H_9)_2NH$	129.15	161	.74	[1] 370	90
$C_8H_{19}N$	Di*iso*butylamine Di*iso*butylamin	$((CH_3)_2CHCH_2)_2NH$	129.15	138.8	.745	224	100
$C_{10}H_{23}N$	Di*iso*amylamine Di*iso*amylamin	$((CH_3)_2CHCH_2CH_2)NH$	157.19	190	.767	[1] 384	0
$C_6H_{11}N$	Diallylamine Diallylamin	$(CH_2{=}CHCH_2)_2NH$	97.86	111	.72	288	100
C_3H_9N	Trimethylamine (33 per cent in water) Trimethylamin	$(CH_3)_3N$	59.077	3.5	.662	[1] 331	0
$C_6H_{15}N$	Triethylamine Triäthylamin	$(C_2H_5)_3N$	101.12	89.5	.728	218	100
$C_9H_{21}N$	Tri-*n*-propylamine Tripropylamin	$(C_3H_7)_3N$	143.17	156	.757	227	100
$C_{12}H_{27}N$	Tri-*n*-butylamine Tributylamin	$(C_4H_9)_3N$	185.22	214	.778	[1] 389	0
$C_{15}H_{33}N$	Tri*iso*amylamine Tri*iso*amylamin	$(C_5H_{11})_3N$	227.26	237	.785	[1] 393	0
$C_{14}H_{13}NO$	Tetramethylammonium hydroxide 10 per cent Tetramethylammoniumhydroxid	$(CH_3)_4NOH$	91.108	[4]	----------	[1] 50	0
C_2H_3N	Acetonitrile Methyl cyanide Äthannitril Acetonitril Methylcyanid	CH_3CN	41.031	82	.783	[1] 392	90
C_3H_5N	Propionitrile Ethyl cyanide Propannitril Propionitril Äthylcyanid	CH_3CH_2CN	55.047	97.1	.783	235	100
C_4H_7N	*n*-Butyronitrile *n*-Propyl cyanide Butannitril Butyronitril Propylcyanid	$CH_3CH_2CH_2CN$	69.062	118	.794	238	100
C_5H_9N	*n*-Valeronitrile *n*-Valeryl nitrile Pentannitril *n*-Valeriansäurenitril *n*-Valeronitril	$CH_3CH_2CH_2CH_2CN$	83.077	141	.801	224	100
$C_6H_{11}N$	*Iso*capronitrile 2-Methyl-pentannitril-(5) *Iso*butylessigsäurenitril *Iso*capronitril	$(CH_3)_2CHCH_2CH_2CN$	97.09	155.5	.806	81	100

[1] The maximum dosage tested.

[4] Decomposes.

TABLE 1.—*Empirical formula, synonyms, structural formula, molecular weight, boiling point, specific gravity, concentration of fumigants, and percentage mortality of weevils after exposure for 24 hours*—Continued

Empirical formula	Compound with synonyms	Structural formula	Molecular weight	Boiling point at 760 mm.	Specific gravity 20°/4°	Minimum lethal dosage of fumigant	Weevils killed after exposure for 24 hours
				° *C.*		*Mg. per liter*	*Per cent*
$C_3H_2Cl_3NO$	Chloral cyanohydrin 2, 2, 2-Trichlorolactic nitrile	$Cl_3CCH(OH)CN$	174.40	220		[1] 500	0
$C_3H_3N_3O_3$	Cyanuric acid	$(HCNO)_3$	129.047			[1] 500	0
CH_3NO_2	Nitromethane Nitromethan	CH_3NO_2	61.031	101.9	1.139	[1] 570	90
$C_2H_5NO_2$	Nitroethane Nitro-äthan	$CH_3CH_2NO_2$	75.047	114.8	1.056	211	100
$C_4H_9NO_2$	*n*-Butyl nitrite *n*-Butylester der saltpetrigen säure	$CH_3CH_2CH_2CH_2ONO$	103.077	75	.911	91	100
$C_5H_{11}NO_2$	*Iso*amyl nitrite *Iso*amylester der saltpetrigen säure *Iso*amylnitrit Amylnitrit	$(CH_3)_2CHCH_2CH_2ONO$	117.09	99	.872	87	100
$C_2H_5NO_3$	Ethyl nitrate Äthylester der saltpetersäure Äthylnitrat Saltpeteräther	$CH_3CH_2ONO_2$	91.047	88.7	1.105	[1] 553	80
$C_5H_{11}NO_3$	*Iso*amyl nitrate *Iso*amylester der saltpetersäure *Iso*amylnitrat	$(CH_3)_2CHCH_2CH_2ONO_2$	133.09	148	.996	239	100
$C_5H_9NO_2$	Diacetyl monomethoxime	$CH_3COC(NOCH_3)CH_3$	115.08	125–127	.9	90	100
CH_5NO	α-Methylhydroxylamine O-Methylhydroxylamin α-Methylhydroxylamin Methoxylamin	CH_3ONH_2	47.047		.9	90	100
C_2H_6S	Ethyl mercaptan Äthanthiol Äthylmercaptan	C_2H_5SH	62.111	36.2	.840	[2] 17	100
C_3H_8S	*n*-Propyl mercaptan Propanthiol-(1) *prim.*-Propylmercaptan *n*-Propylmercaptan	$CH_3CH_2CH_2SH$	76.127	68	.8	48	100
C_3H_8S	*Iso*propyl mercaptan Propanthiol-(2) *sek.*-Propylmercaptan *Iso*propylmercaptan	$(CH_3)_2CHSH$	76.127	60	.8	160	100

$C_4H_{10}S$	*n*-Butyl mercaptan Butanthiol-(1) *prim.*-Normalbutylmercaptan *n*-Butylmercaptan	C_4H_9SH	90. 142	98	. 836	67	100
$C_4H_{10}S$	*Iso*butyl mercaptan 2-Methyl-propanthiol-(1) *Iso*butyl-mercaptan	$(CH_3)_2CHCH_2SH$	90. 142	88	. 836	33	100
$C_5H_{12}S$	*Iso*amyl mercaptan 2-Methyl-butanthiol-(4) *Iso*amylmercaptan	$C_5H_{11}SH$	104. 16	129. 5	. 835	84	100
C_2H_6S	Methyl sulphide Dimethylsulfid	$(CH_3)_2S$	62. 111	36. 2	. 849	425	100
$C_4H_{10}S$	Ethyl sulphide Diäthyl-sulfid	$(C_2H_5)_2S$	90. 142	91. 6	. 837	419	100
$C_6H_{14}S$	*n*-Propyl sulphide Dipropylsulfid	$(C_3H_7)_2S$	118. 17	142	. 814	244	100
$C_8H_{18}S$	*Iso*butyl sulphide Di*iso*butylsulfid	$((CH_2)_2CHCH_2)_2S$	146. 20	171	. 836	334	100
$C_6H_{10}S$	Allyl sulphide Diallylsulfid	$(CH_2{=}CHCH_2)_2S$	114. 14	138. 7	. 888	[1] 444	60
$C_2H_6S_2$	Methyl disulphide Dimethyldisulfid	CH_3SSCH_3	94. 176	118	1. 046	[2] 21	100
$C_4H_{10}S_2$	Ethyl disulphide Diäthyl-disulfid	$C_2H_5SSC_2H_5$	122. 21	153. 5	. 993	79	100
$C_4H_{10}Se$	Ethyl selenide Diäthyl-selenid	$(C_2H_5)_2Se$	137. 28	108	1. 230	246	100
C_2H_4OS	Thioacetic acid Thioessigsäure Thiacetsäure Äthanthiolsäure	CH_3COSH	76. 096	93	1. 074	215	100
$SOCl_2$	Thionyl chloride	$SOCl_2$	118. 981	78. 8	1. 638	655	100
$C_4H_9O_2ClS$	*n*-Butanesulphochloride Butan-sulfonsäure-(1) chlorid Butan-α-sulfonsäure	$CH_3CH_2CH_2CH_2SO_2Cl$		96	1. 2	[1] 600	0
$C_3H_6S_3$	Dimethyl-trithiocarbonate	$SC(SCH_3)_2$	138. 24	204. 5	1. 159	[1] 600	20
$C_7H_{12}S_2$	Mercaptol	$(CH)_2C(SC_2H_5)_2$	160. 22	191	<1.	[1] 600	0
CCl_4S	Perchloromethyl mercaptan	CCl_3SCl	185. 90	149	1. 718	240	100
C_2H_3NS	Methyl thiocyanate Thiocyansäure-methylester Rhodanmethan Methylthiocyanate Methylrhodanid	CH_3SCN	73. 096	133	1. 068	64	100
C_3H_5NS	Ethyl thiocyanate Thiocyansäure-äthylester Rhodanäthan Äthylrhodanid	C_2H_5SCN	87. 112	144. 4	. 996	100	100
C_4H_7NS	*Iso*propyl thiocyanate Thiocyansäure-*iso*propylester *Iso*propylrhodanid	$(CH_3)_2CHSCN$	101. 127	149–151	. 963	[2] 19	100

[1] The maximum dosage tested.

[2] The minimum concentration tested.

TABLE 1.—*Empirical formula, synonyms, structural formula, molecular weight, boiling point, specific gravity, concentration of fumigants, and percentage mortality of weevils after exposure for 24 hours*—Continued

Empirical formula	Compound with synonyms	Structural formula	Molecular weight	Boiling point at 760 mm.	Specific gravity 20°/4°	Minimum lethal dosage of fumigant	Weevils killed after exposure for 24 hours
				° *C.*		*Mg. per liter*	*Per cent*
C_3H_5NS	Ethyl *iso*thiocyanate Thiokohlensäure-äthylimid Äthyl*iso*thiocyanat Äthylsenföl	C_2H_5NCS	87. 112	132	0. 995	[2] 20	100
C_4H_5NS	Allyl*iso*thiocyanate Allyl*iso*thiocyanat Allylsenföl	$CH_2{=}CHCH_2NCS$	99. 112	150. 7	1. 01	[2] 20	100
$C_4H_{10}O_3S$	Ethyl sulphite Diethyl sulfite Diäthylester der schwefligen säure Diäthylsulfite	$(C_2H_5)_2SO_3$	138. 14	161. 3	1. 077	108	100
$C_2H_6O_4S$	Methyl sulphate Dimethylsulfat	$(CH_3)_2SO_4$	126. 111	188. 8	1. 333	667	100

[2] The minimum concentration tested.

DISCUSSION OF RESULTS

In considering the results of the fumigation tests upon weevils in ½-liter glass flasks, it should be borne in mind that the tests were conducted in the presence of a relatively large quantity of wheat, which has a large absorptive capacity for the vapors of many compounds. The minimum lethal dosage is greater, therefore, than if no wheat were present.

The exact minimum lethal concentration of compounds in the vapor phase would have to be determined in the absence of wheat or any other absorptive material, and under carefully controlled conditions of temperature and humidity, and to compare the toxicity of compounds accurately the concentration of vapor should be expressed in terms of gram-molecules per liter, or molar percentage. The minimum lethal dose of each compound as determined in these tests, however, includes the true minimum lethal concentration of vapor plus the quantity of material absorbed by the wheat plus the quantity that failed to volatilize. The tests in this series were made for the sole purpose of rapidly surveying the field of possible fumigants suitable for the destruction of insects in grain, but it is believed that the following information obtained on the relations between the chemical-physical properties of organic compounds and their toxicity to rice weevils is of value.

On account of the experimental error of the tests, results within 20 per cent of each other are rated as equal.

RELATIVE TOXICITY OF THE ALIPHATIC COMPOUNDS TESTED

Hydrocarbons

Of nine hydrocarbons tested, only two, *n*–heptane and diisobutylene, killed all the weevils, and even these were not highly toxic. Aliphatic hydrocarbons of the methane or ethylene series do not appear promising as grain fumigants.

Bromides

Under the conditions of the test the order of toxicity of the bromine substitution products of hydrocarbons is as follows:

Of methane, carbon tetrabromide > bromoform > methylene bromide.
Of ethane, ethylene > ethyl > ethylidene.
Of propane, *n*–propyl > 1, 2–dibromo > *iso*propyl.
Of butane, *tert.*–butyl > *n*–butyl = *iso*butyl > *iso*butylene > *sec.*–butyl.
Of the straight chain bromides, *n*–propyl = *n*–butyl > ethyl.

The alkylene radical appears to be more toxic than the corresponding alkyl one; for example, the toxicity of allyl bromide is greater than that of *n*–propyl bromide.

Two of the bromides, *tert.*–butyl and allyl bromides, killed 100 per cent of the weevils at the minimum [3] dosage tried.

Tetrabromoethane, 1, 2–dibromobutane, 2, 3–dibromobutane, and 1, 2, 3–tribromobutane did not kill all the weevils at the maximum [4] dosage tried.

[3] The minimum dosage of each compound tested was 0.02 c. c. per liter.
[4] The maximum dosage of each compound tested was 0.50 c. c. per liter.

Chlorides

The order of toxicity of the chlorine substituted hydrocarbons is as follows:

Of methane, chloroform>methylene chloride>carbon tetrachloride.
Of ethane, ethylene dichloride>penta=tetra=trichloroethane>ethylidene chloride>hexachloroethane.
Of propane, 1, 2-dichloro>1, 3-dichloro>*n*-propyl=*iso*propyl.
Of butane, *tert.*-butyl>1, 1-dichloro =*n*-butyl.
Of ethene, dichloro=trichloro=tetrachloro.

The following relations are also significant:

*Iso*amyl>*n*-butyl>*n*-propyl.
1, 2-Dichloroethane>1, 1-dichloroethene.
Trichloroethane>trichloroethene.
Tetrachloroethane>tetrachloroethene.

Only one aliphatic chloride tested, hexachloroethane, failed to kill 100 per cent of the weevils at the maximum dosage used.

Iodides

Five of the twelve aliphatic iodides tested killed all weevils at the minimum dosage tried. Iodoform was the only iodide that did not kill all weevils at the maximum dosage tested.

The comparative toxicity of the iodides is as follows:

n-Propyl>*iso*propyl.
*Iso*butyl=*sec.*-butyl>*n*-butyl.
n-Propyl>*n*-butyl>*iso*amyl.

In toxicity to weevils, chlorides, bromides, and iodides rank as follows:

Comparative Toxicity of Chlorides, Bromides, and Iodides

Substitution product of—	Derivative	Order of toxicity
Methane	Di	Iodide>chloride>bromide.
	Tri	bromide>chloride.
	Tetra	bromide>chloride.
Ethane	Mono	Iodide>bromide.
	1, 1-Di	bromide=chloride.
	1, 2-Di	bromide>chloride.
Propane	Mono (1)	Iodide>bromide>chloride.
	Mono (2)	Iodide>bromide>chloride.
	1, 2-Di	bromide=chloride.
Butane	*n*-Butyl	Iodide=bromide>chloride.
	*Iso*butyl	Iodide>bromide.
	sec.-Butyl	Iodide>bromide.
	tert.-Butyl	bromide>chloride.
Pentane	*Iso*amyl	Chloride>bromide=iodide.

Ethylene dibromide>ethylene chlorobromide>ethylene dichloride.

Alcohols

Twenty-four alcohols were tested. Ten, namely, methyl, ethyl, *n*-propyl, *n*-butyl, *n*-amyl, *n*-hexyl, *n*-heptyl, di-*n*-propyl carbinol, *n*-octyl, and *n*-nonyl alcohols, failed to kill all the weevils at the maximum dosage tried. The order of toxicity of the other alcohols is as follows:

tert.-Amyl=methylbutylcarbinol=dimethyl *n*-propyl carbinol> *tert.*-butyl > triethylcarbinol > *iso*butyl = *sec.*-butyl = *sec.*-butylcarbinol=*sec.*–octyl=allyl>*iso*amyl=*sec.*–amyl=diethylcarbinol=*iso*propyl.

None of the straight chain primary alcohols was effective in killing weevils. The branched chain primary alcohols (*iso*butyl alcohol, *iso*amyl alcohol, and *sec.*–butyl carbinol) were effective, but less so than the secondary and tertiary alcohols with the same number of carbon atoms. Of the 5 most toxic alcohols, 4 are tertiary, and 1 is a secondary alcohol.

The following orders of toxicity were ascertained:

*Iso*propyl>*n*–propyl.
tert.–Butyl>*iso*butyl=*sec.*–butyl>*n*–butyl.
tert.–Amyl>*sec.*–butylcarbinol>*iso*amyl=*sec.*–amyl=diethylcarbinol>*n*–amyl.
Methylbutylcarbinol=dimethyl–*n*–propylcarbinol>*n*–hexyl.
Triethylcarbinol>di–*n*–propylcarbinol or *n*–heptyl alcohol.
sec.–Octyl>*n*–octyl.
Allyl>*iso*propyl>*n*–propyl.
Primary alcohols, *iso*butyl=*sec.*–butylcarbinol>*iso*amyl.
Secondary alcohols, methylbutylcarbinol>*sec.*–butyl=*sec.*–octyl>*sec.*–amyl=diethylcarbinol=*iso*propyl.
Tertiary alcohols, *tert.*–Amyl=dimethyl–*n*–propylcarbinol>triethylcarbinol.

Halogen Substituted Alcohols

The comparative toxicity of the halogen substituted alcohols is as follows:

Epichlorohydrin>propylene chlorohydrin>ethylene chlorohydrin>ethylene bromohydrin>trimethylene chlorohydrin or trichloro–*tert.*–butyl alcohol.

Epichlorohydrin was effective at the minimum dosage tried, but trimethylene chlorohydrin and trichloro–*tert.*–butyl alcohol failed to kill all weevils even at the rate of 0.50 c. c. per liter. The substitution of chlorine or bromine for hydrogen in ethyl and *n*–propyl alcohols resulted in an increase in their toxicity to weevils covered with wheat.

Amino Alcohols

β–Dimethylamino ethyl alcohol, the only amino alcohol tested, failed to kill all weevils when applied at the rate of 0.50 c. c. per liter.

Ethers

As a class, the ethers were weak in insecticidal action. Of 11 tested, 8 failed to kill all weevils at the maximum dosage of 0.50 c. c. per liter. The toxicity of the others may be compared as follows:

Di–*n*–propyl=methyl–*n*–amyl=ethyl–*n*–butyl>di*iso*propyl=methyl–*n*–butyl.
Di–*n*–propyl>di*iso*propyl.

There is no consistent relation between the toxicity of the ethers and their corresponding alcohols. For example,

*Iso*propyl alcohol>di*iso*propyl ether, but
Di–*n*–propyl ether>*n*–propyl alcohol.

Oxides

The two oxides tested were highly toxic to weevils in wheat. Ethylene oxide has such a high vapor pressure at room temperature (25° C.) that it was difficult accurately to pipette small quantities of it. Its exact toxic dosage is shown by the tests in the 500-cubic-foot fumigating vault, p. 49.

Halogen Substituted Ethers

Of five halogen substituted ethers tested, two, 2–bromoethyl ethyl ether and 2–chloroethyl ether, killed at the minimum dosage tried. Chloromethyl methyl ether failed to kill all weevils at the maximum dosage, and the dichloromethyl ether had low toxicity.

The position of the substituting halogen atoms affects the toxicity of the compound. For example, 2–chloroethyl ether is much more toxic than 1, 2–dichloroethyl ethyl ether.

Acetals

Ethylal, acetal, and dimethylacetal are about equally toxic, the minimum lethal dosage of each being 340 mg. per liter. Methylal failed to kill all weevils at the maximum dosage of 0.50 c. c. per liter.

Aldehydes

Formaldehyde, applied as the aqueous solution formalin, propionaldehyde, *n*–butyraldehyde, *iso*valeraldehyde, and heptaldehyde failed to kill all weevils at the maximum dosage.

*Iso*butyraldehyde is the most toxic of the aldehydes tested.

The following relations were determined:

*Iso*butyraldehyde>crotonaldehyde>*n*–butyraldehyde.
Acrolein>propionaldehyde.
Aerolein>crotonaldehyde.

Ketones

The order of toxicity of the ketones follows:

Dipropyl ketone>diethyl ketone>dimethyl ketone.

Di–*n*–butyl and di–*n*–amyl ketones did not kill all weevils at the dosage of 0.50 c. c. per liter.

Methyl *iso*butyl ketone>methyl *n*–butyl ketone=methyl *n*–propyl ketone>methyl *n*–amyl ketone=ethyl methyl ketone>dimethyl ketone.

Of all the ketones tested, mesityl oxide is the most toxic to weevils in wheat.

One of the two diketones tried, diacetyl, failed to kill all weevils at the maximum dosage.

Acids

Not one of the nine acids tested killed any weevils at the maximum dosage of 0.50 c. c. per liter. The vapors of these acids appear to be taken up by wheat and thus fail to reach the weevils underneath.

Acid chlorides and bromides

Nine compounds of the acid chloride and bromide class killed no weevils when tested in a dosage of 0.50 c. c. per liter. Wheat appears to retain the vapors of these compounds in the same manner that it does those of the acids.

Esters

formates

The order of toxicity of the formates is as follows:

Methyl=*iso*butyl=allyl>*iso*propyl>ethyl=*n*–propyl=*iso*amyl>*n*–butyl.

Ethyl orthoformate is slightly less toxic than ethyl formate.

CHLOROFORMATES

Nine chloroformate compounds were tested. Methyl chloroformate was found to be more toxic than ethyl chloroformate and this in turn was more toxic than *n*–propyl chloroformate.

β–Chloroethyl chloroformate is less toxic than ethyl chloroformate.

Six chloroformates failed to kill all weevils in wheat even at the maximum dosage.

ACETATES

Ten esters of acetic acid were tried. Two, namely, *n*–heptyl and *sec.*–octyl acetates, failed to kill all weevils at the maximum dosage of 0.50 c. c. per liter. The order of toxicity of the others is:

*Iso*butyl = *n*–propyl>*sec.*–butyl = *iso*propyl>*iso*amyl = methyl = ethyl = *n*–butyl.

HALOGENATED ESTERS OF ACETIC ACID

Bromomethyl and 3–bromopropyl acetates did not kill all the weevils at the maximum dosage. 2–Bromoethyl acetate killed 100 per cent of the weevils at the minimum dosage applied. The toxicity of 2–bromomethyl is greater than that of 2-chloroethyl.

ESTERS OF HALOGENATED ACETIC AND PROPIONIC ACIDS

The following are the orders of toxicity found for the esters of halogenated acetic and propionic acids:

Methyl bromoacetate>methyl chloroacetate.
Ethyl bromoacetate>ethyl chloroacetate.
Methyl chloroacetate>ethyl chloroacetate>*n*–butyl chloroacetate.
Ethyl chloroacetate>ethyl dichloroacetate>ethyl trichloroacetate.
Ethyl 1-bromopropionate>ethyl 2–bromopropionate.
Ethyl bromoacetate>ethyl 1–bromopropionate.

CYANOACETATES

The only ester of cyanoacetic acid tried, ethyl cyanoacetate, failed to kill 100 per cent of the weevils at the maximum dosage.

PROPIONATES

Among the propionates the following order of toxicity was observed:

Ethyl=*n*–propyl>methyl=*iso*butyl>*iso*amyl.

n–Butyl propionate failed to kill all weevils at the maximum dosage.

LACTATES

Two esters of lactic (*α*–hydroxypropionic acid) were tested, methyl and ethyl. Both proved ineffective at the maximum concentration of 0.50 c.c. per liter.

n–BUTYRATES

Four esters of *n*–butyric acid, *n*–propyl, *n*–butyl, *iso*butyl, and *iso*amyl, failed to kill all weevils at the maximum dosage used. Of the other two, the toxicity of the methyl is greater than that of the ethyl.

*ISO*BUTYRATES

Two esters of *iso*butyric acid were tested. The ethyl is more toxic than the *iso*butyl.

n–VALERATES

The methyl ester was the only *n*–valerate that gave a 100 per cent kill. Ethyl and *n*–butyl *n*–valerates were ineffective.

*ISO*VALERATES

The ethyl ester was effective, but the *n*–propyl, *iso*butyl, and *iso*amyl esters failed to kill at the maximum dosage of 0.50 c.c. per liter.

CAPROATES, HEPTYLATES, AND CAPRYLATES

None of the methyl and ethyl esters of the caproic, heptylic, and caprylic acids killed 100 per cent of the weevils at the maximum dosage of 0.50 c. c. per liter.

OXALATES

Neither the dimethyl, diethyl, nor di*iso*amyl esters killed any weevils even at the maximum dosage.

CARBONATES

Six esters of carbonic acid were tested. Only the diethyl ester gave a 100 per cent kill.

DIACETATE AND ACETOACETATE

Ethylidene diacetate and ethyl acetoacetate were ineffective.

ACRYLATE

The only ester of an unsaturated acid that was tried, ethyl β–β-dimethyl acrylate, was effective at a dosage of 203 mg. per liter.

Comparison of Toxicity of Methyl, Ethyl, and *Iso*butyl Esters

The relative toxicity of the methyl, ethyl, and *iso*butyl esters of different fatty acids is shown in Table 2, which gives the minimum lethal dosage of each.

Table 2.—*Toxicity of methyl, ethyl, and* iso*butyl esters of certain fatty acids to rice weevils buried in wheat*

Acid	Minimum lethal dosage (mg. per liter) for 24 hours' exposure of—			Acid	Minimum lethal dosage (mg. per liter) for 24 hours' exposure of—		
	Methyl ester	Ethyl ester	*Iso*butyl ester		Methyl ester	Ethyl ester	*Iso*butyl ester
	Mg.	*Mg.*	*Mg.*		*Mg.*	*Mg.*	*Mg.*
Formic	39	72	35	*n*-Valeric	255	(1)	(2)
Acetic	187	180	87	*Iso*valeric	(2)	173	(1)
Propionic	183	125	174	*n*-Caproic	(1)	(1)	(2)
n-Butyric	180	264	(1)	*n*-Heptylic	(1)	(1)	(2)
*Iso*butyric	(2)	87	263	Caprylic	(1)	(2)	(2)

[1] Five-tenths cubic centimeters, approximately 450 mg., did not kill 100 per cent of the weevils.
[2] Not tested.

From the data in Table 2 it is evident that the esters of formic acid are markedly more toxic to weevils in wheat than are the esters of the higher acids.

The esters of the branched chain acids are more toxic than those of the corresponding straight chain acids having the same number of carbon atoms. For example,

Ethyl *iso*butyrate>ethyl *n*–butyrate.
*Iso*butyl *iso*butyrate>*iso*butyl *n*–butyrate.
Ethyl *iso*valerate>ethyl *n*–valerate.

Effect of Halogen Substitution in Esters

IN THE ACID RADICAL

The esters of chloroformic acid are decidedly less toxic to weevils covered with wheat than are the corresponding esters of formic acid. This is attributed to the great instability of the chloroformates. Apparently most of their vapors are absorbed by the wheat before they come in contact with the weevils. For instance,

Methyl formate>methyl chloroformate.
Ethyl formate>ethyl chloroformate.

The introduction of a single chlorine or bromine atom in acetic acid greatly increases the toxicity of the esters. For example:

Methyl chloroacetate>methyl acetate.
Ethyl chloroacetate>ethyl acetate.

The introduction of two or three chlorine atoms in acetic acid, however, decreases the toxicity of the esters. In that case the following is the order of toxicity:

Ethyl chloroacetate>ethyl acetate>ethyl dichloroacetate>ethyl trichloroacetate.

The introduction of a single bromine atom in the alpha position into propionic acid increases the toxicity of the ethyl ester, but in the beta position decreases the toxicity.

Ethyl 1–bromopropionate>ethyl propionate>ethyl 2–bromopropionate.

IN THE ALKYL RADICAL

No consistent relations in toxicity seem to hold when halogen is substituted in the alkyl radical.

Methyl acetate>bromomethyl acetate.
Propyl acetate>3–bromopropyl acetate, but
2–Bromo and 2–chloroethyl acetates>ethyl acetate.

The following comparison shows this inconsistency:

2–Chloroethyl acetate>ethyl chloroacetate, but
Methyl bromoacetate>bromomethyl acetate.

Amines

PRIMARY AMINES

None of the primary amines exhibits much toxicity to weevils in wheat. The following comparisons were made:

*Iso*propyl>*n*–propyl.
sec.–Butyl>*iso*butyl>*n*–butyl.
*Iso*amyl>*n*–amyl.

Four out of ten primary amines failed to kill all weevils when applied at the rate of 0.50 c. c. per liter.

SECONDARY AMINES

The following order of toxicity of the secondary amines was observed:

Di*iso*propyl>diethyl>di-*n*-propyl=di*iso*butyl>diallyl.
Di*iso*butyl>di-*n*-butyl.

TERTIARY AMINES

Three out of five tertiary amines tested, namely, trimethyl, tri-*n*-butyl, and tri*iso*amylamines, failed to kill all the weevils. Triethyl and tri-*n*-propylamines are about equally toxic.

QUATERNARY AMINES

The only quaternary ammonium derivative tested, tetramethylammonium hydroxide, failed to kill any weevils in wheat at the maximum dosage of 0.50 c. c. per liter.

COMPARISON OF PRIMARY, SECONDARY, AND TERTIARY AMINES

An exact comparison of the amines can not be made, because so many tested failed to kill 100 per cent of the weevils. The toxicity of diethylamine, however, is greater than that of triethylamine, which in turn is greater than the toxicity of monoethylamine. In general, the secondary amines appear to be more toxic than the primary or tertiary amines.

Nitriles

The nitriles are toxic in the following order:

*Iso*capro>*n*-valero=propio=*n*-butyro.

Acetonitrile was not effective in killing 100 per cent of the weevils in wheat at the maximum dosage.

Chloral cyanohydrin and cyanuric acid killed no weevils at the maximum dosage.

NITRO COMPOUNDS, NITRITES, NITRATES, OXIMES, AND HYDROXYLAMINES

In toxicity the nitro compounds, nitrites, nitrates, oximes, and hydroxylamines rank as follows:

Nitroethane>Nitromethane.
n-Butyl nitrite=*iso*amyl nitrite.
*Iso*amyl nitrate>ethyl nitrate.
*Iso*amyl nitrite>*iso*amyl nitrate.

Diacetyl monomethoxime and α-methylhydroxylamine are about equally toxic, the minimum lethal dosage of each being 90 mg. per liter.

Mercaptans

As a class, the mercaptans are extremely toxic. Ethyl mercaptan killed all the weevils in wheat at the minimum dosage tried, 0.02 c. c. per liter. The order of toxicity of the mercaptans is as follows:

Ethyl>*iso*butyl>*n*-propyl>*n*-butyl>*iso*amyl>*iso*propyl.

As shown in Table 3, the mercaptans are much more toxic to weevils in wheat than are the corresponding alcohols.

TABLE 3.—*Toxicity of mercaptans and alcohols to rice weevils buried in wheat*

Radical	Minimum lethal dosage (mg. per liter) for 24 hours' exposure of—		Radical	Minimum lethal dosage (mg. per liter) for 24 hours' exposure of—	
	Mercaptan	Alcohol		Mercaptan	Alcohol
	Mg.	*Mg.*		*Mg.*	*Mg.*
Methyl	[1]	[2]	*n*-Butyl	67	[2]
Ethyl	[3] 17	[2]	*Iso*butyl	33	160
n-Propyl	48	[2]	*Iso*amyl	84	195
*Iso*propyl	160	220			

[1] Not tested.
[2] Five-tenths cubic centimeter, approximately 400 mg., did not kill 100 per cent of the weevils.
[3] Minimum dosage tried.

SULPHIDES

The comparative toxicity of the sulphides is as follows:

n-Propyl>*iso*butyl>ethyl=methyl>allyl.

The sulphides are distinctly less toxic to weevils in wheat than are the corresponding mercaptans. For example,

Ethyl mercaptan (17)[5]>diethyl sulphide (419).[6]
n-Propyl mercaptan (48)[6]>dipropyl sulphide (244).[6]
*Iso*butyl mercaptan (33)[6]>di*iso*butyl sulphide (334).[6]

DISULPHIDES

Only two disulphides were tested, methyl and ethyl. The methyl is more toxic than the ethyl.

The disulphides are much more toxic than the sulphides, but somewhat less toxic than the mercaptans. For example,

Methyl disulphide>methyl sulphide.
Ethyl mercaptan>ethyl disulphide>ethyl sulphide.

SELENIDES

The only selenide tested, ethyl selenide, was more toxic than the corresponding sulphide, ethyl sulphide.

MISCELLANEOUS SULPHUR COMPOUNDS

Butanesulphochloride, dimethyltrithiocarbonate, and mercaptol did not kill all weevils at the maximum dosage of 0.50 c. c. per liter.

The other sulphur compounds tested, namely, thioacetic acid, thionyl chloride, and perchloromethyl mercaptan, were only slightly to moderately toxic to weevils in wheat.

THIO– AND *ISO*THIOCYANATES

The following order of toxicity exists among the thiocyanates:

*Iso*propyl>methyl>ethyl.

[5] Minimum dosage tried. [6] Minimum lethal dosage.

The *iso*thiocyanates are more toxic than the corresponding thiocyanates, ethyl *iso*thiocyanate, for instance, being more toxic than ethyl thiocyanate.

Ethyl and allyl *iso*thiocyanates killed all weevils at the minimum dosage.

Sulphites and sulphates

Ethyl sulphite, the only sulphite tried, was more toxic to weevils in wheat than was methyl sulphate, the one sulphate tested.

Comparative Toxicity of Alkyls

The difference in toxicity of the methyl, ethyl, and *n*–propyl derivatives is, in general, so slight that the results of the tests are not sufficiently accurate to establish the proper order of toxicity. Furthermore, these tests were made on a basis of milligrams per liter rather than milligram molecules per liter. It was noticed, however, that the *n*–propyl derivative is more toxic than the *iso*propyl derivative in the bromide, chloride, iodide, ether, acetate, and mercaptan, whereas the *iso*propyl derivative is more toxic in the alcohol, formate, primary amine, and secondary amine.

The general order of toxicity of the butyl derivatives is as follows:

tert.–Butyl > *iso*butyl = *sec.*–butyl > *n*–butyl.

Every *tert.*–butyl derivative tested (bromide, chloride, and alcohol) was more toxic than the corresponding *n*– and *sec.*–butyl derivatives.

The *iso*butyl derivative is more toxic than the *n*–butyl in the iodide, alcohol, aldehyde, ketone (methyl *iso*butyl ketone > methyl *n*–butyl ketone), formate, acetate, propionate, primary amine, secondary amine, and mercaptan. *n*–Butyl and *iso*butyl bromides are about equally toxic.

The unsaturated radical, allyl, appears to have more toxicity than the *n*–propyl radical.

The allyl is more toxic than the *n*–propyl in the bromide, alcohol, aldehyde, and formate, but *n*–propyl sulphide is more toxic than allyl sulphide.

MOST EFFECTIVE FUMIGANTS

The fumigants shown in these tests to be the most effective are grouped in the following list:

Part 1.—Fumigants Lethal in the Minimum Dosage Applied (0.02 c. c. per Liter)

	Mg. per liter		Mg. per liter
Ethyl mercaptan.....Less than..	17	Allyl bromide........Less than..	28
*Iso*propyl thiocyanate.....do....	19	2-Bromoethyl acetate.....do....	30
Ethyl *iso*thiocyanate......do....	20	Methyl bromoacetate.....do....	30
Allyl *iso*thiocyanate.......do....	20	Ethyl bromoacetate.......do....	30
Methyl disulphide........do....	21	*n*–Propyl iodide...........do....	35
tert.–Butyl bromide.......do....	24	Allyl iodide...............do....	37
Epichlorohydrin..........do....	24	Ethyl iodide..............do....	39
2-Chloroethyl ether.......do....	24	Methyl iodide.............do....	46
2-Bromoethyl ethyl ether..do....	27	Methylene iodide.........do....	67

Ten classes of compounds are represented in this list of 18 effective fumigants, namely, 2 bromides out of 20 tested; 5 iodides out of 12 tested; the 1 epichlorohydrin tested; 2 halogenated ethers out of 5 tested; 1 halogenated ester out of 4 tested; 2 esters of halogenated fatty acids out of 19 tested; 1 mercaptan out of 6 tested; 1 disulphide out of 2 tested; 1 thiocyanate out of 3 tested; and both *iso*thiocyanates tested.

Thirteen of these 18 compounds contain halogen, and the remaining 5 contain sulphur. Three of the sulphur compounds also contain nitrogen.

PART 2.—ADDITIONAL FUMIGANTS LETHAL IN DOSAGES LESS THAN 100 MG. PER LITER

	Mg. per liter		Mg. per liter
Ethylene oxide	20	Di*iso*propylamine	72
*Iso*butyl mercaptan	33	Methyl chloroacetate	73
tert.–Butyl chloride	34	*Iso*butyraldehyde	79
*Iso*butyl formate	35	*tert.*–Butyl alcohol	79
Allyl formate	38	Ethyl disulphide	79
Methyl formate	39	*Iso*capronitrile	81
2–Chloroethyl acetate	47	*n*–Propyl bromide	81
n–Propyl mercaptan	48	Methyl *n*–butyl ketone	83
Mesityl oxide	52	Ethyl 1–bromopropionate	84
*Iso*propyl formate	53	*Iso*amyl mercaptan	84
Propylene oxide	54	Ethyl *iso*butyrate	87
Carbon tetrabromide	60	*Iso*butyl acetate	87
*Iso*butyl iodide	64	Ethylene dibromide	87
sec.–Butyl iodide	64	*Iso*amyl nitrite	87
Methylbutylcarbinol	64	Propylene chlorohydrin	89
Methyl*iso*butyl ketone	64	*n*–Propyl acetate	89
Methyl thiocyanate	64	Diacetyl monomethoxime	90
tert.–Amyl alcohol	65	α–Methylhydroxylamine	90
Dimethyl *n*–propylcarbinol	66	Ethyl orthoformate	90
n–Butyl mercaptan	67	*n*–Butyl nitrite	91
*Iso*propyl iodide	68	Ethyl chloroacetate	93
*Iso*amyl formate	70	Methyl *n*–propyl ketone	97
Ethyl formate	72	*n*–Butyl iodide	97
n–Propyl formate	72	Ethyl thiocyanate	100

The effective compounds in part 2 of this list represent the following proportion of each class:

Three bromides out of 20 tested; 1 chloride out of 21 tested; 4 iodides out of 12 tested; 1 secondary alcohol out of 8 tested; 3 tertiary alcohols out of 11 tested; 4 ketones out of 11 tested; 1 secondary amine out of 8 tested; 2 nitrites out of 2 tested; 1 nitrile out of 5 tested; 8 formates (including 1 orthoformate) out of 9 tested; 2 acetates out of 10 tested; 1 *iso*butyrate out of 2 tested; 2 monochloroacetates out of 3 tested; 1 bromopropionate out of 2 tested; the 1 oxime tested; the 1 hydroxylamine tested; 1 halogenated ester out of 4 tested; 2 thiocyanates out of 3 tested; 4 mercaptans out of 7 tested; 1 disulphide out of 2 tested; and both oxides tested.

Of these 48 compounds, 13 contain halogen, 8 contain nitrogen, 7 contain sulphur, 2 contain both sulphur and nitrogen, and 22 contain only carbon, hydrogen, and oxygen.

Of the 309 compounds tested, 243 were either nontoxic under the conditions of the test, or more than 100 mg. per liter was required to kill the insects.

LEAST EFFECTIVE FUMIGANTS

The following materials failed to kill any weevils at the maximum dosage of 0.50 c. c. per liter: Decane, amylene, *sym.*–tetrabromoethane, 1, 2, 3–tribromobutane, hexachloroethane, iodoform, methyl alcohol, *n*–butyl alcohol, *n*–amyl alcohol, *n*–hexyl alcohol, *n*–heptyl alcohol, *n*–octyl alcohol, *n*–nonyl alcohol, trimethylene chlorohydrin, β–dimethylaminoethyl alcohol, di–*n*–amyl ether, di*iso*amyl ether, glycol ethyl ether, chloromethyl ether, formalin, propionaldehyde, *n*–butyraldehyde, heptaldehyde, di–*n*–butyl ketone, di–*n*–amyl ketone, diacetyl, formic acid, acetic acid, chloroacetic acid, propionic acid, *n*–butyric acid, *iso*butyric acid, *n*–valeric acid, *iso*valeric acid, dl–methylethylacetic acid, bromoacetyl bromide, chloroacetyl chloride, di–chloroacetyl chloride, trichloroacetyl chloride, propionyl chloride, *n*–butyryl chloride, *n*–valeryl chloride, *iso*valeryl chloride, *n*–butyl chloroformate, *iso*amyl chloroformate, *n*–heptyl acetate, *sec.*–octyl acetate, γ–bromopropyl acetate, ethyl cyanoacetate, methyl lactate, ethyl lactate, *n*–butyl *n*–butyrate, *iso*butyl *n*–butyrate, *n*–butyl *n*–valerate, *n*–propyl *iso*valerate, *iso*butyl *iso*valerate, *iso*amyl *iso*valerate, methyl *n*–caproate, ethyl *n*–caproate, methyl *n*–heptylate, ethyl *n*–heptylate, methyl *n*–caprylate, methyl oxalate, ethyl oxalate, *iso*amyl oxalate, di–*n*–propyl carbonate, di–*n*–butyl carbonate, di*iso*amyl carbonate, ethylidene diacetate, ethyl acetoacetate, methylamine, ethylamine, *n*–propylamine, *n*–butylamine, *n*–amylamine, dimethylamine, di*iso*amylamine, trimethylamine, tri–*n*–butylamine, tri*iso*amylamine, tetramethylammonium hydroxide, chloral cyanohydrin, cyanuric acid, *n*–butanesulphochloride, and mercaptol.

These 85 nontoxic compounds represent the following proportion of the various classes: Two hydrocarbons out of 9 tested; 2 bromides out of 20 tested; 1 chloride out of 21 tested; 1 iodide out of 12 tested; 7 primary alcohols (all straight chain) out of 12 tested; 1 chlorohydrin out of 4 tested; the 1 amino alcohol tested; 3 ethers out of 11 tested; 1 chloro–ether out of 4 tested; 4 aldehydes out of 10 tested; 2 ketones out of 11 tested; 1 diketone out of 2 tested; the 9 acids tested; the 9 acid bromides and chlorides tested; 2 chloroformates out of 9 tested; 2 acetates out of 10 tested; 1 brominated ester out of 4 tested; the 1 cyanoacetate tested; both lactates tested; 2 *n*–butyrates out of 6 tested; 1 *n*–valerate out of 3 tested; 3 *iso*valerates out of 4 tested; both caproates tested; both heptylates tested; the 1 *n*–caprylate tested; the 3 oxalates tested; 3 carbonates out of 6 tested; the 1 diacetate tested; the 1 acetoacetate tested; 5 primary amines out of 10 tested; 2 secondary amines out of 8 tested; 3 tertiary amines out of 5 tested; the 1 tetramethylammonium derivative tested; the 1 cyanohydrin tested; the 1 cyanuric acid tested; the 1 sulphochloride tested; and the 1 miscellaneous sulphur compound tested.

CONCLUSIONS

A study of the 66 most toxic and the 85 least toxic compounds from a total of 309 tested against weevils in the presence of wheat under conditions where the compounds could come in contact with the weevils only in the vapor phase indicates:

Apparently no relation exists between the boiling point of compounds and their relative toxicity, except that most compounds of high boiling point (above 150° C.) have too low a vapor pressure at room temperature (25° C.) to furnish a toxic concentration of vapor.

Branched chain radicals are more toxic than are straight chain radicals.

Chemically inert compounds, that is, paraffin hydrocarbons, have but little toxicity.

Some compounds that are highly reactive chemically, such as aldehydes, acids, and acid chlorides, do not kill weevils in wheat, probably because they are absorbed by the wheat and fail to reach the insects.

Compounds belonging to the following classes are the most toxic: Iodides, bromides, mercaptans, thiocyanates, *iso*thiocyanates, disulphides, oxides, epichlorohydrin, halogenated ethers, halogenated esters, and formates.

GERMINATION TESTS

METHOD

In order to determine the usefulness of a fumigant, its effect upon the germinating quality of seeds must be known. To obtain information regarding the action upon wheat germination of the various compounds tested as fumigants for the rice weevil in this investigation, careful germination tests were made upon the wheat, before and after 24 hours' exposure to each fumigant. In most cases the fumigated wheat was treated with the maximum dosage of fumigant tested, namely, 0. 5 c. c. per liter of space half filled with wheat, equivalent to 1. 25 c. c. per kilogram of grain. These germination tests were made in duplicate upon 100 kernels of wheat by the seed testing laboratory, Bureau of Plant Industry.

EXPERIMENTAL RESULTS

The fumigants that lowered the comparative germination of wheat more than 10 per cent are given in Table 4.

TABLE 4.—*Fumigants that lower the germination of wheat 10 per cent or more of check*

Fumigant	Dosage applied	Minimum lethal dosage	Germination of fumigated wheat expressed as percentage of check	Fumigant	Dosage applied	Minimum lethal dosage	Germination of fumigated wheat expressed as percentage of check
	Gm. per kg. of wheat	*Gm. per kg. of wheat* [1]	*Per cent*		*Gm. per kg. of wheat*	*Gm. per kg. of wheat* [1]	*Per cent*
Allyl bromide	0. 3	[2] 0. 07	2	Chloroacetic acid	1. 25	>[3] 1. 25	32
Do	1. 7	[2]. 07	4	Bromoacetyl bromide	2. 9	>[3] 2. 90	17
Methyl iodide	. 6	[2]. 115	1	Chloroacetyl chloride	1. 5	>[3] 1. 87	21
Allyl iodide	. 3	[2]. 090	86	Dichloroacetyl chloride	1. 5	>[3] 1. 95	85
Do	1. 4	[2]. 090	27	Trichloroacetyl chloride	1. 6	>[3] 2. 04	89
Methyl alcohol	3. 5	>[3]. 99	89	*n*-Butyryl chloride	1. 3	>[3] 1. 28	89
Do	13. 1	>[3]. 99	80	*n*-Valeryl chloride	1. 3	>[3] 1. 27	85
Ethyl alcohol	10. 3	>[3] 1. 98	50	*Iso*valeryl chloride	1. 2	>[3] 1. 24	88
n-Butyl alcohol	5. 5	>[3] 1. 01	65	Oxalyl chloride	1. 9	>[3] 1. 86	68
2-Bromoethyl alcohol	2. 1	. 84	56	Allyl formate	1. 2	. 1	87
α-Epichlorohydrin	1. 5	[2]. 06	0	Methyl chloroformate	. 6	. 5	68
α-β-Dichloroethyl ether	. 6	. 47	78	Do	1. 5	. 5	9
Do	1. 5	. 47	10	Ethyl chloroformate	. 7	. 63	42
Ethylene oxide	. 075	[2]. 05	0	*n*-Propyl chloroformate	1. 4	>[3] 1. 36	13
Do	4. 4	[2]. 05	0	*n*-Butyl chloroformate	1. 3	>[3] 1. 35	74
Propylene oxide	1. 1	. 13	0	*Iso*butyl chloroformate	1. 3	>[3] 1. 3	76
Formalin	1. 25	>[3]. 5	69	Bromoethyl acetate	2. 0	>[3] 1. 88	76
Acetaldehyde	2. 0	>[3] 1. 17	0	2-Bromoethyl acetate	2. 0	[2]. 07	89
Heptaldehyde	1. 1	>[3] 1. 06	87	γ-Bromopropyl acetate	. 7	>[3] 1. 5	78
Acrolein	1. 1	. 42	1	Do	1. 5	>[3] 1. 5	88
Crotonaldehyde	1. 1	. 86	1	Methyl monochloroacetate	. 3	. 18	13
Chloroacetone	1. 45	. 29	0	Do	1. 5	. 18	1
Diacetyl	1. 2	>[3] 1. 22	1	Ethyl monochloroacetate	. 3	. 23	10
Formic acid	. 5	>[3] 1. 5	89	Do	1. 5	. 23	2
*Iso*valeric acid	1. 2	>[3] 1. 17	87	*Iso*propyl monochloroacetate	. 3	[2]. 05	16
dl-Methylethylacetic acid	1. 2	>[3] 1. 18	88				

[1] Data in this column are calculated from figures in minimum-lethal-dosage column of Table 1.
[2] Minimum dosage tested, equivalent to 0.02 c. c. per liter or 0.05 c. c. per kilogram of wheat.
[3] Maximum dosage tested, equivalent to 0.5 c. c. per liter or 1.25 c. c. per kilogram of wheat.

TABLE 4.—*Fumigants that lower the germination of wheat 10 per cent or more of check*—Continued

Fumigant	Dosage applied	Minimum lethal dosage	Germination of fumigated wheat expressed as percentage of check
	Gm. per kg. of wheat	*Gm. per kg. of wheat* [1]	*Per cent*
*Iso*propyl monochloroacetate	1.5	[2] .05	4
n-Butyl monochloroacetate	1.3	.5	6
Ethyl dichloroacetate	1.6	.6	22
Ethyl trichloroacetate	1.7	1.7	88
Methyl monobromoacetate	.4	[2] .07	26
Do	1.9	[2] .07	1
Ethyl monobromoacetate	.4	[2] .07	41
Do	1.9	[2] .07	4
Ethyl propionate	.7	.31	89
Ethyl α-bromopropionate	1.0	.21	82
Do	1.7	.21	23
*Iso*amyl *n*-butyrate	1.1	>[3] 1.1	89
n-Butyl *n*-valerate	1.1	>[3] 1.1	85
Ethyl *n*-caproate	1.1	>[3] 1.1	86
Methyl oxalate	1.4	>[3] 1.25	30
Ethyl oxalate	1.4	>[3] 1.35	59
*Iso*amyl oxalate	1.2	>[3] 1.2	89
Di*iso*amylamine	.95	>[3] .96	77
Triethylamine	.9	.55	89
Tri-*n*-butylamine	1.0	>[3] .97	84
Tri*iso*amylamine	1.0	>[3] .98	71
Ethyl nitrate	.8	>[3] 1.38	2
n-Butyl nitrite	1.1	.23	51
Methyl sulphide	1.1	1.06	89
Thioacetic acid	1.3	.54	89
Thionyl chloride	2.0	1.64	0
n-Butanesulphochloride	1.25	>[3] 1.5	87
Perchloromethyl mercaptol	1.25	.60	7
Methyl sulphate	1.7	1.67	31

[2] Minimum dosage tested, equivalent to 0.02 c. c. per liter or 0.05 c. c. per kilogram of wheat.
[3] Maximum dosage tested, equivalent to 0.50 c. c. per liter or 1.25 c. c. per kilogram of wheat.

DISCUSSION OF RESULTS AND CONCLUSIONS

Several of the compounds tested, for example, acids and acid chlorides, injure the germination of wheat and are not effective against weevils.

Some of the compounds that lower the percentage germination of wheat were tested in excessive doses, for instance, α-epichlorohydrin.

Only a few of the materials that hold promise as insecticides must be used cautiously upon seed grain. These are certain iodides, halogenated alcohols, epichlorohydrin, halogenated ethers, oxides, and esters of halogenated fatty acids.

The bromides, with the exception of allyl bromide, chlorides, formates, sulphides, disulphides, thiocyanates, *iso*thiocyanates, and mercaptans, in dosages more than sufficient to kill all weevils in wheat do not injure the germination of the grain.

TESTS IN A 500-CUBIC-FOOT FUMIGATING VAULT [7]

METHOD

Of the 66 compounds that under laboratory conditions were 100 per cent toxic to the rice weevil at dosages less than 100 mg. per liter or 6.24 pounds per 1,000 cubic feet, only a few possess the desirable

[7] Detailed accounts of the tests with the most promising of the fumigants will be found in the following publications:

COTTON, R. T., and ROARK, R. C. ETHYLENE DICHLORIDE—CARBON TETRACHLORIDE MIXTURE; A NEW NONBURNABLE, NONEXPLOSIVE FUMIGANT. Jour. Econ. Ent. 20: 636–639. 1927.

——— and ROARK, R. C. FUMIGATION OF STORED-PRODUCT INSECTS WITH CERTAIN ALKYL AND ALKYLENE FORMATES. Indus. and Engin. Chem. 20: 380–382. 1928.

——— and ROARK, R. C. ETHYLENE OXIDE AS A FUMIGANT. Indus. and Engin. Chem. 20: 805. 1928.

ROARK, R. C., and COTTON, R. T. FUMIGATION TESTS WITH CERTAIN ALIPHATIC CHLORIDES. Jour. Econ. Ent. 21: 135–142. 1928.

——— and COTTON, R. T. INSECTICIDAL ACTION OF SOME ESTERS OF HALOGENATED FATTY ACIDS IN THE VAPOR PHASE. Indus. and Engin. Chem. 20: 512–514. 1928.

qualities of cheapness, effectiveness, commercial availability, and freedom from fire hazard and injurious effect upon man or merchandise.

Seventeen of the compounds that possess some or all of these qualifications were selected as worthy of further testing. A series of experiments with these was conducted in a commercial-type fumigating vault which was of very tight construction and had a capacity of 500 cubic feet. The fumigant to be tested was poured through a trap door in the top of the vault into a shallow trough suspended close to the ceiling. The vault was then closed for 24 hours. The insects used were the larvae of the clothes moth (*Tineola biselliella*), of the black carpet beetle (*Attagenus piceus*), and of the furniture beetle (*Anthrenus vorax*), all species highly resistant to fumigants. The larvae were placed in cotton-stoppered vials and buried in pieces of overstuffed furniture. In all tests 20 specimens of the clothes moth and 50 specimens of each of the other species were used.

In addition to these tests comparative tests with carbon tetrachloride and carbon disulphide were made.

EXPERIMENTAL RESULTS

Table 5 contains data indicating the relative toxicity of the various compounds or mixtures of compounds tested. With the exception of carbon disulphide and ethylene oxide, the vapors of the compounds, or a mixture of a compound and carbon tetrachloride, used in the experiment are nonflammable and nonexplosive when heated to 122° F. and may therefore be considered as free from fire hazard.

TABLE 5.—*Results of fumigation tests on insects in a 500-cubic-foot vault*

Class	Fumigant				Temperature	Minimum lethal dosage for an exposure of 24 hours
	Compound	Parts by volume	Compound	Parts by volume		
					° F.	*Pounds for 1,000 cubic feet*
Chlorides	Carbon tetrachloride				85	30
	do	1	Ethylene dichloride	3	85	6
	do	1	do	3	65	12
	do	7	*tert.*-Butyl chloride	3	83	12
	Trichloroethylene				83	12
	Tetrachloroethylene				85	30
Iodides	Carbon tetrachloride	3	Ethyl iodide	1	85	5
Alcohols	do	7	*tert.*-Butyl alcohol	3	85	20
Oxides	Ethylene oxide				75	1
Formates	Carbon tetrachloride	7	*n*-Propyl formate	3	85	11
	do	3	*Iso*propyl formate	1	85	14
	do	3	*sec.*-Butyl formate	2	85	8
	do	3	*Iso*butyl formate	2	85	9
	do	3	*Iso*amyl formate	2	85	7
Acetates	do	7	*Iso*propyl acetate	3	83	15
Monochloroacetates.	Methyl monochloroacetate				83	1
	Ethyl monochloroacetate				83	2
	*Iso*propyl monochloroacetate				83	1½
Carbonates	Carbon tetrachloride	1	Diethyl carbonate	1	83	30+
Disulphides	Carbon disulphide				80	1½

DISCUSSION OF RESULTS AND CONCLUSIONS

The data in Table 5 show that several of the compounds are sufficiently toxic to be of value as fumigants. Ethylene oxide and methyl monochloroacetate appear to be the most toxic of the compounds tested, and when used in a tight vault compare favorably in toxicity with carbon disulphide. Others somewhat less toxic have advantages that compensate for the lower toxicity and enhance their value for fumigation of some types. Some of the advantages and limitations of these materials are discussed below.

CHLORIDES

The chlorides as a group are cheap, commercially available in large quantities, not highly toxic to man, and not readily flammable. They possess pleasant odors, and do not affect the germination of wheat. Of the several chlorides tested on a large scale, ethylene dichloride in a mixture of 3 volumes to 1 volume of carbon tetrachloride appears to be the most promising as a general fumigant. At 85° F. or over, a complete kill is obtained with 6 pounds of the mixture per 1,000 cubic feet of space. At lower temperatures a somewhat larger dose is required to give equally good results. The 3 to 1 mixture is nonflammable, nontoxic to man, and harmless to fabrics and furniture. It does not affect the germinating qualities of wheat, but gives to foodstuffs rich in oil a characteristic sweetish taste, which they are likely to retain for some time. In Industrial and Engineering Chemistry for February, 1930, ethylene dichloride in tank cars is quoted at 8 cents per pound, f. o. b.

Although more toxic than ethylene dichloride, *tert.*–butyl chloride requires a larger proportion of carbon tetrachloride to render it free from fire hazard, and it can not be used in metal-lined vaults because it attacks the metal.

Trichloroethylene is nonflammable and in the large scale tests proved to be about two and a half times as toxic as carbon tetrachloride at 80° F. or over. It should be valuable for combining with more toxic compounds to reduce the fire hazard.

Tetrachloroethylene, also nonflammable, is about as toxic as carbon tetrachloride.

IODIDES

Ethyl iodide, the only iodide tested on a large scale, is highly toxic, but owing to its high cost and the improbability of its being produced cheaply in the near future, it can not be considered a practical fumigant.

ALCOHOLS

Tertiary butyl alcohol is the most toxic of the alcohols tested. As the vapors are flammable, however, such a large proportion of carbon tetrachloride must be added to remove the fire hazard that the toxicity of the resulting mixture is reduced to a prohibitive extent.

OXIDES

Ethylene oxide shows promise of being an excellent all-purpose fumigant. A gas at ordinary temperatures, it is put up in liquid form under pressure. The gas is almost odorless, and so far as known has no injurious effect upon merchandise. Owing to its low boiling point, 10.7° C., it is effective at comparatively low temperatures, a feature that greatly enhances its value. The vapors are flammable and in high concentrations produce anaesthesia in man. In a concentration of 1 pound per 1,000 cubic feet, however, the fire and human hazards are negligible. The 1930 price of ethylene oxide is about $2 a pound in small quantities or 75 cents a pound in large quantities. It could probably be made to sell in large quantities at about 40 cents a pound.

FORMATES

The vapors of the lower alkyl formates are highly toxic to insects, and by admixture with carbon tetrachloride, formates that boil above 70° C. can be made free from fire hazard. The vapors are not injurious to the germinating power of grain and seem well adapted for the fumigation of foodstuffs. The esters of formic acid are now commercially available. When these formates are used as fumigants, a temperature of 75° F. or more is essential to obtain the best results.

ACETATES

Tests with *iso*propyl acetate indicated that so large a proportion of carbon tetrachloride must be added to obtain a mixture free from fire hazard that the effectiveness is reduced too low for practical purposes.

MONOCHLOROACETATES

The monochloroacetates tested on a large scale are highly toxic at 80° F. and above. Owing to their high boiling point they are not efficient at low temperatures. Their vapors have a slightly irritating effect upon the eyes, but their lachrymatory power is much less than that of chloropicrin. Very little is known regarding the physiological action of monochloroacetic acid and its esters. The vapors of these esters, heated to 122° in admixture with air in a box will not propagate a flame when sparked and therefore may be said to be free from fire hazard. In small lots ethyl monochloroacetate has been quoted at from $1 to $1.50 a pound. It is believed that it could be manufactured in moderate quantities to sell at not more than 30 cents a pound. The methyl and *iso*propyl esters could probably be made to sell for not more than 50 cents a pound.

The results of germination tests on wheat fumigated with these monochloroacetates indicate that they have an injurious effect upon the germination.

CARBONATES

When mixed with a quantity of carbon tetrachloride sufficient to remove the fire hazard the vapors of diethyl carbonate are not toxic enough to be of commercial value.

SUMMARY

Three hundred and nine aliphatic compounds were tested against the rice weevil in ½-liter Erlenmeyer flasks half filled with wheat. Sixty-six of these compounds were lethal after an exposure of 24 hours, in dosages less than 100 mg. per liter or 6.24 pounds per 1,000 cubic feet, 18 of these being lethal in the minimum dosage tried, 0.02 c. c. per liter (1 to 4 pounds per 1,000 cubic feet).

The compounds showing the greatest toxicity are in the following classes: Iodides, bromides, mercaptans, thiocyanates, *iso*thiocyanates,

disulphides, oxides, epichlorohydrin, halogenated ethers, halogenated esters, and formates.

An analysis of the results obtained with the 66 most toxic and the 85 least toxic compounds tested indicates that there is no apparent relation between the boiling point of compounds and their relative toxicity, except that most compounds having a high boiling point (above 150° C.) have too low a vapor pressure at room temperature to furnish a toxic concentration; that branched chain radicals are more toxic than are straight chain radicals; that compounds which are inert chemically have little toxicity; and that some compounds highly reactive chemically do not kill weevils in wheat, probably because they are absorbed by the wheat and fail to reach the insects.

Germination tests with wheat showed that the chlorides, formates, sulphides, disulphides, thiocyanates, *iso*thiocyanates, and mercaptans in dosages more than sufficient to kill weevils do not injure the germination of the grain. The iodides, halogenated alcohols, epichlorohydrin, halogenated ethers, oxides, and esters of halogenated fatty acids are injurious to the germination of wheat and should be used with caution.

Many effective compounds are unavailable commercially or are too costly to be of practical value. Seventeen compounds showing promise of commercial value were tested in a 500-cubic-foot fumigation vault. Two of these, ethylene oxide and methyl monochloroacetate, were shown to be slightly more toxic than carbon disulphide. They were lethal at a dosage of 1 pound per 1,000 cubic feet. The ethyl and *iso*propyl esters of monochloroacetic acid were only slightly less toxic.

Ethylene dichloride in admixture with carbon tetrachloride in the ratio of 3 parts to 1 by volume was lethal at a dosage of 6 pounds per 1,000 cubic feet. Because of its low cost, effectiveness, and lack of fire hazard and toxicity to human beings, ethylene dichloride should be a useful fumigant.

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TECHNICAL BULLETIN No. 161 — DECEMBER, 1929

UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

LIFE HISTORY, HABITS, AND CONTROL OF THE MORMON CRICKET[1]

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CONTENTS

INTRODUCTION

The work reported in this bulletin was begun in Hot Springs County, Wyo., in 1923 by F. W. Boyd.[3] Experimental work dealing with the life history, habits, and control of the Mormon cricket was carried on by Mr. Boyd in that section until 1924. Little or no work was done in 1925, but in 1926 and 1927 the writer did similar work in Lake and Sanders Counties in western Montana. As a sequel to this experimental work a control campaign was instituted by the State of Montana in 1927, in cooperation with these counties. So highly successful was it that another campaign, based on its results, was carried on by the writer in the spring of 1928 in Routt and Moffat Counties, in northwestern Colorado. Here the Mormon cricket had been harmful since 1920, and had already directly or indirectly caused at least half of the homesteaders to desert their homes; and it was feared that if its ravages were not checked the country would be practically depopulated.

[1] *Anabrus simplex* Hald. Order Orthoptera, family Tettigoniidae, subfamily Decticinae.
[2] Resigned June 30, 1928.
[3] Of the Bureau of Entomology, United States Department of Agriculture, formerly located at the field laboratory at Billings, Mont.

Demonstration work was carried on in cooperation with the office of the State entomologist of Colorado, and with Routt and Moffat Counties, during the spring and summer of 1928, but owing to a shortage of available funds the work was limited. At the present writing (spring of 1929), preparations are under way to apply the results of this work in a comprehensive dusting campaign for the control of this pest in Routt and Moffat Counties, Colo., with Craig as the center of operations. Because most of the infestation is known to originate on lands held under public domain, the Federal Government is purchasing the poison and machinery required in applying it, and the ranchers have agreed to supply the necessary labor. The State of Colorado will furnish expert supervision for the project.

HISTORICAL

The first recorded occurrence of the Mormon cricket as an agricultural pest dates from 1848 in the Great Salt Lake Basin in Utah, and is best described by the following quotation from Bancroft (*1, p. 279–281*)[4]:

> The Spring [1848] saw everybody busy, and soon there were many flourishing gardens, containing a good variety of vegetables. In the early part of March ploughing commenced. The spring was mild and rain plentiful, and all expected an abundant harvest. But in the latter part of May, when the fields had put on their brightest green, there appeared a visitation in the form of vast swarms of crickets, black and baleful as the locust of the Dead Sea. In their track they left behind them not a blade or leaf, the appearance of the country which they traversed in countless and desolating myriads being that of a land scorched by fire. They came in a solid phalanx from the direction of Arsenal Hill, darkening the earth in their passage. Men, women, and children turned out en masse to combat this pest, driving them into ditches or on to piles of reeds, which they would set on fire, striving in every way, until strength was exhausted, to beat back the devouring host. But in vain they toiled, in vain they prayed; the work of destruction ceased not, and the havoc threatened to be as complete as that which overtook the land of Egypt in the last days of Israel's bondage. "Think of their condition," says Mr. Cannon—"the food they brought with them almost exhausted, their grain and other seeds all planted, they themselves 1,200 miles from a settlement or place where they could get food on the east, and 800 miles from California, and the crickets eating up every green thing, and every day destroying their sole means of subsistence for the months and winter ahead."
>
> I said in vain they prayed. Not so. For when everything was most disheartening and all effort spent, behold, from over the lake appeared myriads of snow-white gulls, their origin and their purpose alike unknown to the newcomers! Was this another scourge God was sending them for their sins? Wait and see. Settling upon all the fields and every part of them, they pounced upon the crickets, seizing and swallowing them. They gorged themselves. Even after their stomachs were filled they still devoured them. On Sunday the people, full of thankfulness, left the fields to the birds, and on the morrow found on the edges of the ditches great piles of dead crickets that had been swallowed and thrown up by the greedy gulls. Verily, the Lord had not forgotten to be gracious!
>
> To escape the birds, the crickets would rush into the lake or river, and thus millions were destroyed. Toward evening the gulls took flight and disappeared beyond the lake, but each day returned at sunrise, until the scourge was past. Later grasshoppers seem to have taken the place of crickets. They were of a kind popularly called iron-clad, and did much mischief.

In commemoration of this great service a very imposing monument was erected in honor of the gulls just within the gates to the temple grounds in Salt Lake City, Utah. Since 1848 the Mormon

[4] Reference is made by italic numbers in parentheses to "Literature cited," p. 28.

cricket has periodically caused more or less trouble to farmers in most of the States in the Rocky Mountain region. A glance at the accompanying map (fig. 1) will give an idea of the location of the outbreaks of this insect. The shaded portion denotes approximately its chief distribution, and the black spots the localities where outbreaks of it are known to have occurred and where they seem likely to occur again.

The name "Mormon" was probably adopted because of the incident just mentioned, and "cricket" because the insect somewhat resembles

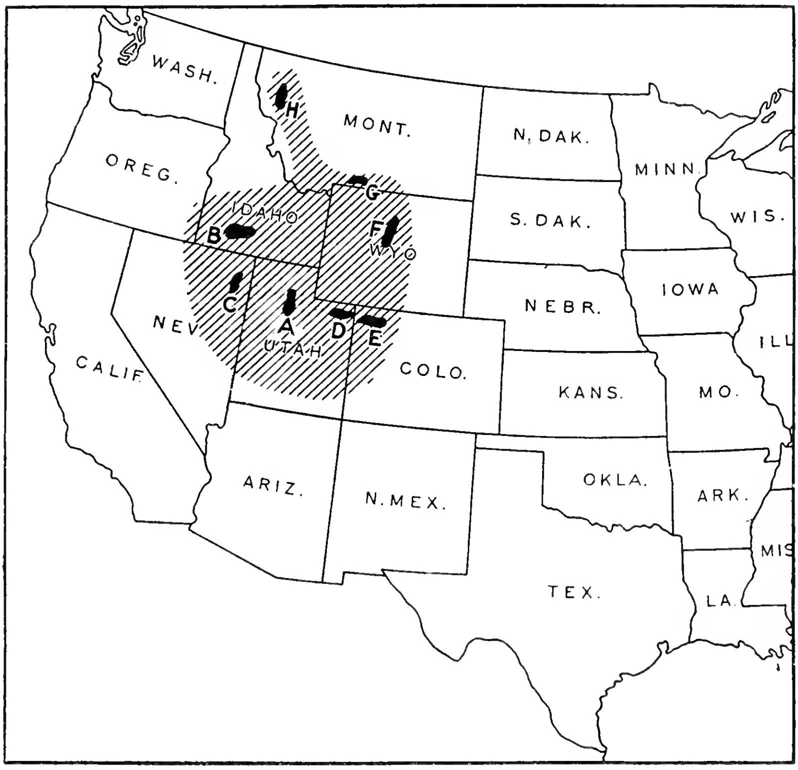

FIGURE 1.—Map of the western part of the United States, showing approximately by the shaded portion the chief distribution of the Mormon cricket. The black spots indicate the localities where outbreaks of the insects are known to have occurred, in the years named in connection with the reference letters: A, 1847–48; B, 1872, 1883, 1894, and 1904; C 1904; D, 1923–1926; E, 1879, 1895, 1900, 1902, 1905, and 1922–1928; F, 1923–1925; G, 1923; H, 1924–1928

the common black field cricket, especially its chirping noises. Technically speaking, however, this insect is not a cricket, but a wingless, long-horned grasshopper.

GEOGRAPHICAL DISTRIBUTION

The Mormon cricket is essentially an insect of the mountains, although it is known to be present in many of the States occupying the Great Plains. Thomas (*7, p. 431*), in 1872, referring to *Anabrus* *purpurascens*, now considered a variety of *A. simplex*, made this statement:

> *Anabrus purpurascens* is found, not abundantly, but at certain elevated points from Northern New Mexico to Montana, along the east base of the mountains, but I have met with no specimen west of the range in the middle district, though Mr. Uhler gives Washington Territory as a locality, on the authority of Dr. Suckley. It is also found as far south as Texas, and as far north as Red River, in Northern Minnesota. *A. simplex* appears to be confined to the middle district, as I have not met with it east of the range, and have seen no notice of it being found either in the eastern or western districts. Dr. Scudder, who examined the *orthoptera* collected by Professor Hayden, in Nebraska, does not mention it in his list; nor did Mr. C. R. Dodge have it among his collections made in Nebraska, Colorado, Kansas, and Indian Territory; nor is it among the collections in the Agricultural Department made east of the Rocky Mountains. Hence I think we may safely conclude that it is confined to the west side of the range. But what it lacks in range is made up in numbers, for in the northern part of Salt Lake Basin and southern part of Idaho, the only points where I have met with it, it is to be seen in armies of myriads. But a fuller account of it will be found in the list.

In the same article (*7, p. 438*), in the "list," appears the following under the heading *Anabrus simplex* Hald.:

> Found in great abundance between Brigham City, Utah, and Fort Hall, Idaho. Also occasionally met with farther south in Utah and north of Fort Hall to the boundary line of Montana, which is here along the range separating the waters of the Atlantic from the Pacific.

The Mormon cricket has also been reported from the prairies of Manitoba by Criddle (*6*).

HABITAT

The natural habitat of *Anabrus simplex* seems to be in broken mountainous country more or less covered with sagebrush and native grasses, a type of country usually termed "scab land." Typical of it is that territory lying in Moffat, Routt, and Rio Blanco Counties, Colo., which embraces the Danforth Hills and Williams River Mountains. Southern Idaho and portions of eastern Oregon typify the natural habitat, as do also the Big Horn Mountains in Wyoming and that part of Montana lying in the eastern half of Sanders County and the northwestern part of Lake County. In these high, rugged hills the cricket can be found year after year, and it is only occasionally that it becomes plentiful enough to leave its natural surroundings and migrate into the cultivated valleys, to cause damage to crops. Such outbreaks usually last from two to six years, or until they are overcome by man, natural enemies, or weather conditions.

ECONOMIC IMPORTANCE

These periodical outbreaks have been occurring in certain localities in the West ever since farming secured a foothold there. The actual money value of crops destroyed by the Mormon cricket is difficult to estimate, because most of the records of its outbreaks are rather indefinite on this point. There is, however, enough information available to show that it is a pest of economic importance so far as the Rocky Mountain region is concerned.

In Moffat County, Colo., the cricket has been at least partially, if not wholly, the cause of a reduction in the number of farms under cultivation in the infested territory from 429 in 1920 to 258 in 1927. The damage caused by the insect in 1922 in that county was estimated at $15,000 to $20,000 (*3*). In 1927 all crops in the newly infested territory in Routt County were damaged from 10 to 75 per cent. The loss in native grasses to the cattlemen in these counties is an item of considerable importance each year, although it is not possible even to estimate it.

It was estimated that in 1926 alone the farmers in Lake and Sanders Counties, Mont., lost more than 100,000 bushels of wheat because of the cricket. This loss, coupled with that of alfalfa, small fruits, and gardens, brought the total valuation of crops lost from this cause to approximately $125,000. In 1925 the loss was not so great, but probably amounted to several thousand dollars. These instances are the only ones in which estimates of damage to crops have been attempted, but undoubtedly outbreaks have occurred in other localities, in which the resulting damage was as great as or greater than in those here mentioned.

EXTENT OF INFESTATIONS

Crickets usually occur in bands varying in extent from the area of a city block to that of a square mile or even more. In the early stages of their development there may be as many as from 100 to 500 crickets per square foot. As they develop in size they spread over a larger area, but still remain pretty much in their respective bands. It is usually possible to find the outer limits of these bands, but in case of a severe infestation they may be so close together as to merge into one enormous horde covering thousands of acres.

NATURE OF INJURY

Damage to cereal crops often occurs in the spring, but as a rule it is not very important. The real injury is caused by the adult crickets after the grain is headed, while it is in the milk and dough stage (fig. 2), and even after it is cut and shocked. At these times only the heads are attacked and stripped of their kernels. During outbreaks of the grasshopper the heads of the cereal are as a rule left intact and will yield some grain, but in case of attack by crickets a badly damaged field yields practically nothing, not even enough to pay for harvesting. Figure 3 represents a field of winter wheat in western Montana completely ruined by Mormon crickets and Figure 4 a near view of standing plants in that field the heads of which have been stripped of their kernels by the crickets.

Alfalfa may be damaged at any time in the season, although the first crop ordinarily is damaged more seriously than either of the succeeding ones, owing to the fact that the grain is heading at about the time the first crop of alfalfa is being cut, and the crickets then ordinarily leave the alfalfa to enter the grain crops.

Garden crops are considered a delicacy by the Mormon cricket and are often eaten to the ground by it as fast as they make their appearance. Small fruits of all kinds are readily eaten and the bushes are stripped of their fruit as soon as it is formed.

SEASONAL HISTORY

Ordinarily the Mormon cricket completes its series of instars and reaches the adult stage between June 15 and July 15, and at the age of 10 days or 2 weeks the female cricket begins to lay eggs. Egg laying continues through July and August, and often into September. By the time frost occurs in the fall the eggs contain fully developed embryos, and are ready to hatch with the first warm days of spring. The exact date of hatching is very uncertain. In 1926, in Montana, a few crickets were hatched by the end of February, and the hatching was completed by March 20. In the same State, in 1927, the hatching occurred somewhat later and was not completed until some time in April. In Colorado, in 1928, a few crickets were hatched by the end of March, whereas in 1929 none were hatched until about April 15.

FIGURE 2.—Wheat heads stripped of their kernels by the Mormon cricket

Usually the seven nymphal stages cover from 75 to 90 days, extending from the date of hatching, as just described, to the time the adult emerges from the seventh molt, which may occur from early in June to the middle of July or later.

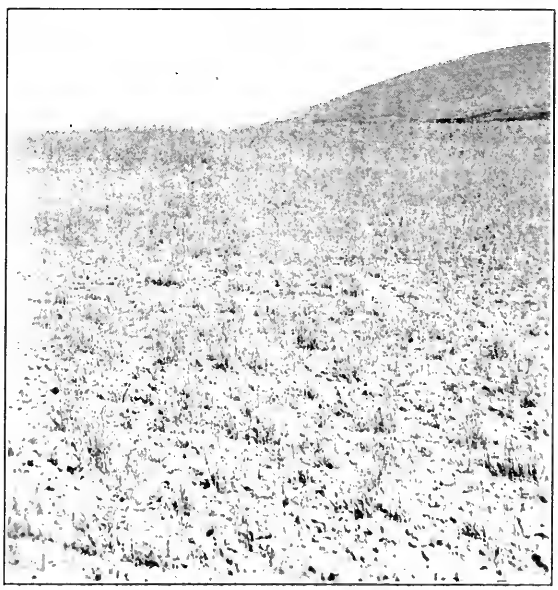

FIGURE 3.—Field of winter wheat in western Montana completely ruined by the Mormon cricket. This field should have produced 20 bushels per acre

The adult female, as has been stated, begins at the age of 10 days or 2 weeks to lay eggs, perhaps at any time in July or a little earlier or later, and continues this work for probably a month or more. Fertilization precedes egg laying by a very short interval. It seems impossible in the present state of our knowledge to estimate with any approach to definiteness the average or the maximum length of life of the adult Mormon cricket. Table 2, page 20, presents the egg-laying performance of 15 female crickets in captivity, from the beginning of egg laying, in the case of each one, to the time of death. The shortest interval between these limits was 8 days and the longest 36, the average being about 26. But the life period of such insects in captivity is not a safe basis for estimating the life period under natural conditions. The hardiness of the crickets and their habit of seeking shelter under which they can withstand long periods of cold and of inclement weather favor longevity, whereas their habit of cannibalism and the fact that there are large numbers of predatory enemies which feed upon them reduce the likelihood of longevity.

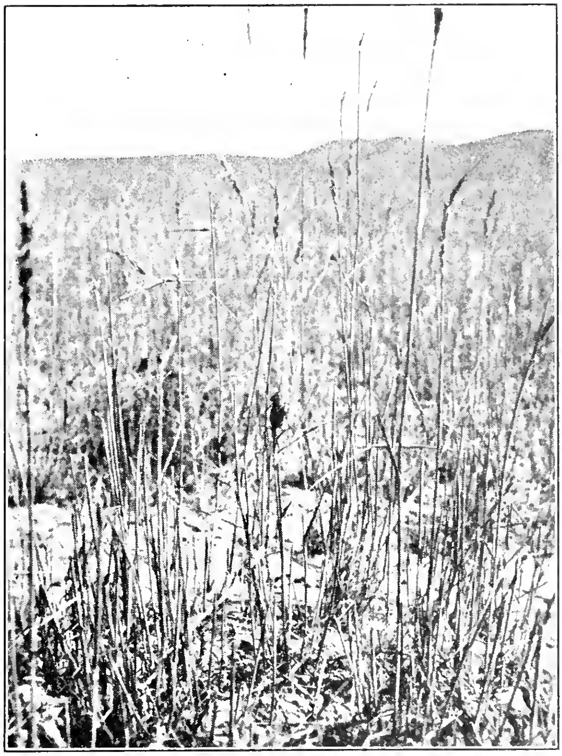

FIGURE 4.—Near view of standing wheat plants in field shown in Figure 3. The heads of wheat have suffered the characteristic injury caused by the Mormon cricket

EXPERIMENTS IN REARING

The insects used in the writer's experiments in rearing were hatched from eggs taken in the field during the fall. These eggs were brought into the laboratory, where they were kept in cold storage until needed. They were then placed in moist sand in suitable receptacles, and incubated at room temperatures ranging from 65° to 85° F. Hatching took place within four or five days, and the nymphs were placed singly in glass tubes 1½ by 8 inches in size and kept at the room temperatures mentioned. One end of each tube was closed with scrim, and a cork having a hole bored through it, covered with fine copper screen, was inserted at the other. The nymphs were supplied each day with a diet of sprouted wheat, lettuce leaves, apples, or onions. An examination was made each day for molted skins, and the date of the molt was recorded on the outside of the tube. A male and a female of each instar were photographed, and drawings were made of the last abdominal segments of each.

Table 1, compiled from notes by F. W. Boyd, gives rearing records for 16 individual crickets held at room temperatures ranging from 70° to 80° F. In each instance seven instars were recorded, and in all more recent experiments in rearing carried on in this laboratory that number has remained unchanged. The total time required from hatching to maturity ranges from 40 to 58 days, with an average of 50 days for the 16 individuals. The time required in nature usually is somewhat longer, being about 75 to 90 days. This difference is probably brought about by the greater variation in temperatures in the field, the very low temperature usually experienced in the early spring months having a tendency to retard the development.

TABLE 1.—*Rearing records of 16 individual Mormon crickets kept at room temperatures ranging from 70° F. to 80° F.*

Cricket No.	Duration of each instar							Total period from hatching to adult stage
	First	Second	Third	Fourth	Fifth	Sixth	Seventh	
	Days	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*
1	7	11	6	4	9	5	9	51
2	8	14	6	8	4	6	11	57
3	9	9	4	4	9	5	9	49
4	9	11	5	7	6	5	11	54
5	9	10	4	4	8	5	8	48
6	8	12	5	10	3	7	7	52
7	11	5	4	6	6	5	13	50
8	10	7	5	5	5	6	12	50
9	11	4	4	8	5	6	14	52
10	12	5	7	7	7	7	13	58
11	8	7	4	7	5	4	8	43
12	12	4	5	7	4	5	15	52
13	10	5	6	6	5	6	7	45
14	11	5	6	6	4	6	11	49
15	7	5	6	8	4	5	5	40
16	10	4	4	7	5	6	14	50
Average	9.5	7.4	5.1	6.5	5.6	5.6	10.4	50.0

DESCRIPTION OF STAGES

EGG

The egg of the Mormon cricket is 7 to 8 millimeters in length, 2 to 2.5 millimeters in diameter, and tapered slightly at each end, and is protected by a thick, leathery chorion. It is laid in almost any type of soil, and under almost any condition of soil covering. When first laid, it is dark brown, changing almost immediately to a milky white on exposure to the soil. After remaining in the soil for some time, the egg gradually acquires a grayish color, which it maintains throughout the stage. As the egg is incubated in the soil the anterior end becomes swollen, owing to the growth of the head and thoracic regions of the young cricket, until, at the time of hatching, it is quite noticeably larger.

The length and breadth of 100 eggs were measured during the winter by F. W. Boyd. As the embryos were almost fully developed at this time the eggs were larger than when first deposited. The lengths ranged from 7 to 8 millimeters, with an average of 7.47; the widths averaged 2.12 millimeters, ranging from 2 to 2.5. Figure 5 represents a pile of 870 eggs collected from 1 square foot of soil.

The eggs are deposited in the soil at a depth of from one-fourth to 1 inch, and are laid singly, but often several eggs are laid by the same female in close proximity to one another. There seems to be no especial arrangement of the eggs in the soil, since they have been observed lying at practically all angles to one another.

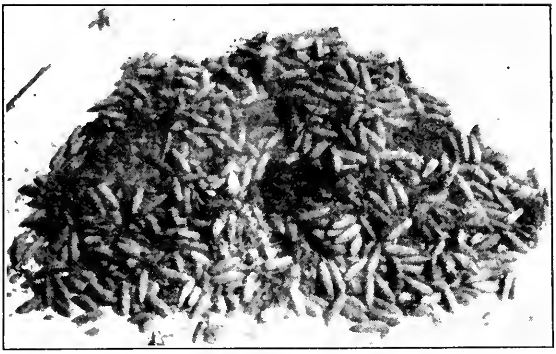

FIGURE 5.—Eggs of the Mormon cricket, numbering 870, taken from 1 square foot of soil

FIRST INSTAR

When an egg is ready to hatch, the chorion splits lengthwise over the anterior end to about half way down the side. The young cricket, protected by the vitelline membrane, wriggles upward through the soil to the surface, where this protective sheath is discarded. On emergence the cricket is about one-fourth inch in length. It is then light tan in color, as it is immediately after each molt, but on exposure to the air it turns black in about an hour. The only markings are a wide band of white on the lateral posterior edges of the prothorax and a light stripe down the back, extending from the head to the tip of the abdomen. On emergence the body at first is quite stout and robust, but as the cricket feeds it becomes more elongate. In Figure 6 is represented the female, A, and the male, B, of the first instar, each enlarged about 5 diameters.

FIGURE 6.—First instar of the Mormon cricket: A, Female; B, male. Enlarged about 5 diameters

Without the aid of a microscope it is impossible to distinguish between the sexes at this stage. However, a close examination of the ventral portions of the last abdominal segments shows plainly the six valves of the ovipositor of the female (fig. 7, A) and the subgenital plate of the male. (Fig. 7, B.) In this stage the rudimentary claspers of both sexes are of about the same size and show no distinguishable difference.

SECOND INSTAR

When the cricket is about a week or 10 days old the first molt takes place, and the insect emerges having the characteristic tan color, which soon changes to black, after which there are no distinguishable changes as to color and markings. Figure 8 represents the female (A) and the male (B) of the second instar, each enlarged about 3 diameters. A closer examination of the apical abdominal segments shows that the inside pair of valves of the ovipositor of the female have become distinctly divided and have increased in length. The inside pair are as yet plainly visible. (Fig. 9, A.) Little change can be observed in the male, except a slight growth in the subgenital plate and a subsequent narrowing of the angle between the two lobes. (Fig. 9, B.)

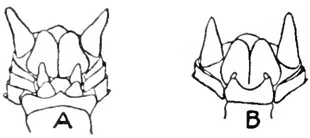

FIGURE 7.—First instar of the Mormon cricket: A, Ventral view of ovipositor of female; B, ventral view of subgenital plate of male. Enlarged 16 diameters

THIRD INSTAR

The second molt is an exact repetition of the first, there being no appreciable change in color or markings. (Fig. 10, A, B.) In the

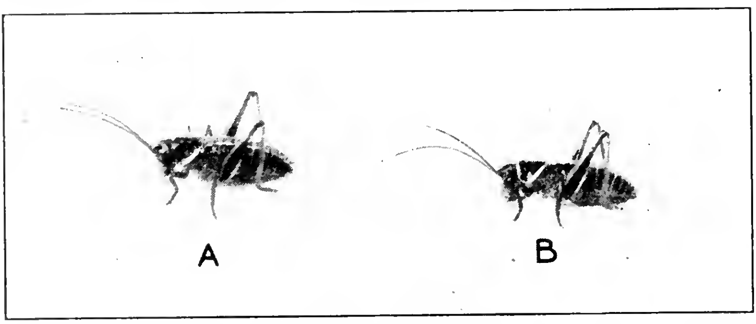

FIGURE 8.—Second instar of the Mormon cricket; A, Female; B, male. Enlarged about 3 diameters

third instar, however, the ovipositor is plainly visible to the naked eye, although it does not as yet extend to the tip of the abdomen. Examination of the ovipositor with a binocular microscope shows that the inner pair of valves are completely incased in the two outer pairs. (Fig. 11, A.) No difference can be seen in the claspers of the two sexes. (Fig. 11, A, B.) The two lobes of the subgenital plate of the male have increased in length, with a further narrowing of the angle at the base and a lessening of the distance between the lobes. (Fig. 11, C.)

FOURTH INSTAR

In the first three instars the insects all become uniformly black shortly after hatching and after each molt, but in the fourth instar (Fig. 12) a variation in color is sometimes observed, the colors ranging from green to brown or black. The ovipositor of the female has become twice as long as that borne in the previous instar, and extends well past the tip of the abdomen. (Figs. 12, A, and 13, A.) In this instar is to be seen the first indication of a difference in the claspers of the two sexes—those of the male begin to flatten on the inside and to curve inward. (Fig. 13, C.) The first signs of bifurcation are also noticed in the male cerci, while those of the female remain round and straight, and never increase greatly in size with further growth.

FIGURE 9.—Second instar of the Mormon cricket: A, Ventral view of ovipositor of female; B, ventral view of subgenital plate of male. Enlarged about 8 diameters

FIFTH INSTAR

In the fifth instar (fig. 14) the insect is somewhat increased in size, and the variation in color is even more marked than in the preceding instar. The ovipositor of the female has again doubled in size, being now about one-third of the length of the hind femur. (Figs. 14, A, and 15, A, B.) The cerci of the male are much more developed, being now quite noticeably branched and curved. (Fig. 15, C, D.)

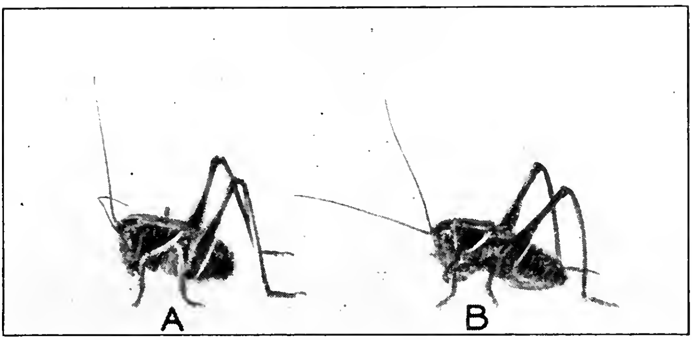

FIGURE 10.—Third instar of the Mormon cricket: A, Female; B, male. Enlarged about 3 diameters

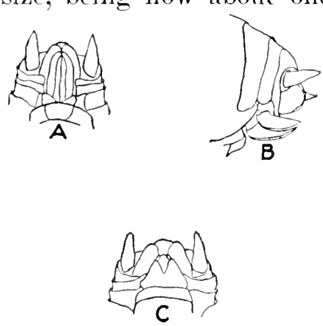

FIGURE 11.—Third instar of the Mormon cricket: A, Ventral view of ovipositor of female; B, side view of same; C, ventral view of subgenital plate of male. Enlarged 8 diameters

SIXTH INSTAR

In the sixth instar (fig. 16) the ovipositor of the female is again doubled in length, being now three-fifths of the length of the hind femur. (Figs. 16, A, and 17, A, B.) The upper hook of the clasper of the male is now quite prominent, but remains blunt and rounded, while the lower one is decidedly hooked and pointed. (Figs. 16, B, 17, C, D.)

SEVENTH INSTAR

In the seventh instar (fig. 18) the ovipositor of the female is once more doubled in length, it being now a little longer than the hind femur. (Fig. 19, A, C.) The claspers of the male are about fully developed, both lobes being pointed and hooked. In the case of both sexes this instar closely resembles the adult in size and shape, but closer examination of the rudimentary wings shows them to be not so fully developed as they are in the adult.

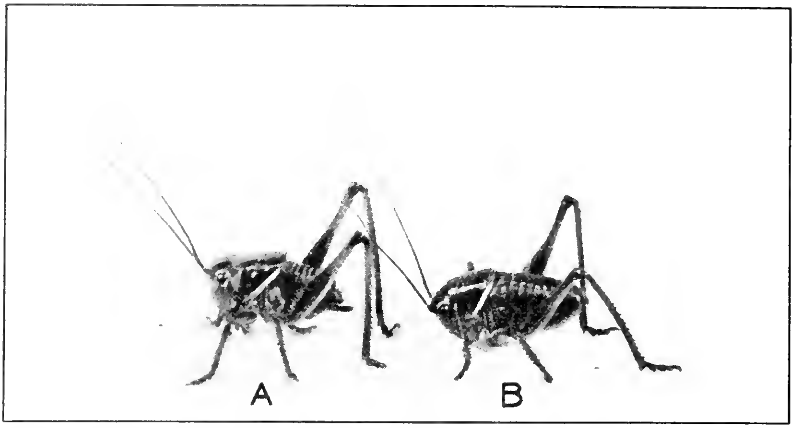

FIGURE 12.—Fourth instar of the Mormon cricket: A, female; B, male. Enlarged 3 diameters

ADULT

The ovipositor of the adult female, although not relatively longer than in the seventh instar, is much heavier and thicker at the base. (Figs. 20, A, and 21, A.) The wings of both sexes have reached their highest development, those of the female meeting at the middle of the back, but not showing from under the prothoracic shield. (Fig. 20, A.) The wings of the male are much longer, showing plainly from underneath the prothoracic shield and overlapping somewhat to form a stridulating organ. (Fig. 20, B.) The ovipositor of the female and the claspers of the male are shown in Figure 21.

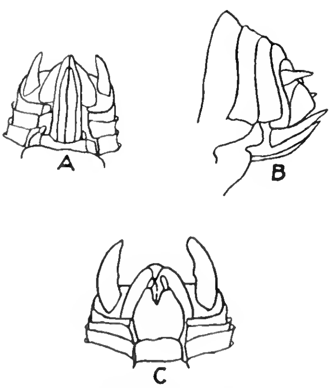

FIGURE 13.—Fourth instar of the Mormon cricket: A, Ventral view of ovipositor of female; B, side view of same; C, ventral view of subgenital plate of male. Enlarged about 8 diameters

MOLTING

The molting of the young crickets is a very interesting process to watch and usually takes from 10 to 20 minutes. When an individual is ready to molt, it climbs up on a stem of grass or any other convenient object and fastens itself securely by its hind feet, with the head pointing downward. As soon as the feet are securely fastened convulsive muscular contractions begin to take place within the body, forcing it upward so that pressure is brought to bear on the dorsal surface of the integument. Soon the integument begins to split along the dorso-median line, commencing above the eyes and extending backward to about midway of the abdomen. The vent thus produced is forced open by further muscular contractions, until the upper part of the thorax is visible. The body is then slowly withdrawn from the old skin by a series of twisting movements of the body from side side to side, commencing with the head and continuing with the mandibles, the antennæ, and the two anterior pairs of legs. The hind femora are then withdrawn, with the aid of the front legs and with further twistings of the body, and finally the tip of the abdomen emerges. On freeing itself from the cast-off skin the insect sometimes drops to the ground, where it remains inactive until the new covering has hardened and turned black. In case it does not drop to the ground it frequently turns and eats the cast-off skin left hanging to

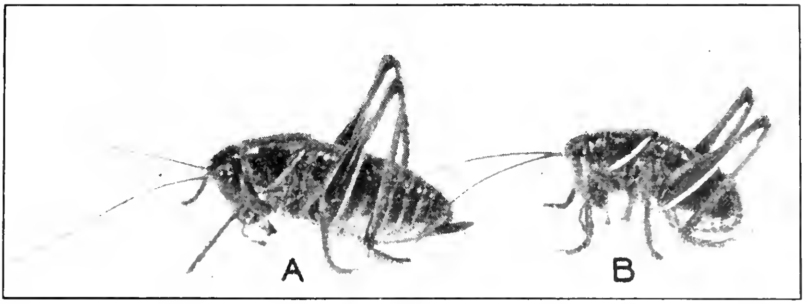

FIGURE 14.—Fifth instar of the Mormon cricket: A, Female; B, male. Enlarged 3 diameters

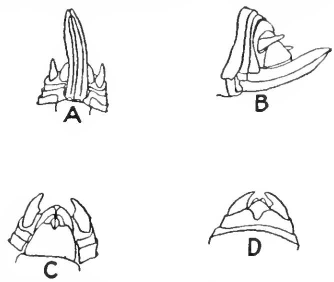

FIGURE 15.—Fifth instar of the Mormon cricket: A, Ventral view of ovipositor of female; B, lateral view of same; C, ventral view of subgenital plate of male; D, dorsal view of same. Enlarged 4 diameters

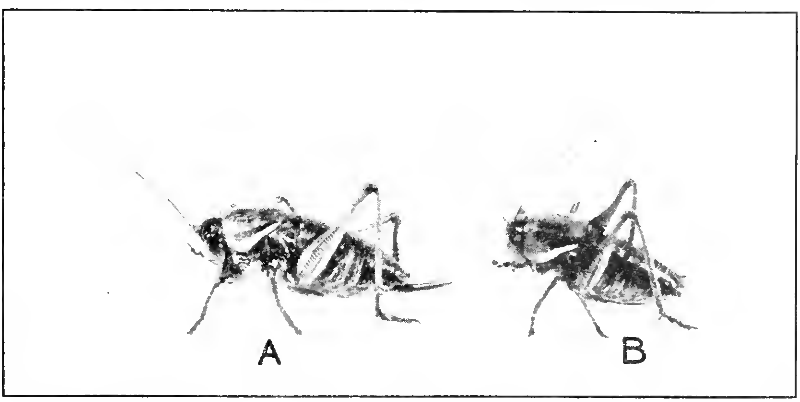

FIGURE 16.—Sixth instar of the Mormon cricket: A, Female; B, male. About natural size

the supporting stem. In rearing tubes the cast-off skin is almost always eaten.

REACTIONS

The Mormon crickets are, as a rule, inclined to be timid. On approaching a "bunch" of them gathered together on a bare spot surrounded by heavy vegetation one has to be cautious in order to get very close. As soon as the presence of an intruder is noticed they all immediately scamper for shelter and soon lose themselves in the vegetation. It is interesting to observe the effect of a sudden motion on a migrating band. Those nearest the source jump away from it, thus exciting others near by, and the motion spreads out in waves resembling those produced by casting a stone into a quiet pool of water. These waves gradually subside as the distance from the source is increased, until they die out entirely. When for any reason one cricket is disturbed it immediately jumps as far as possible in a lateral direction away from the cause of the excitement. This sudden movement is taken up by other crickets until, beginning at the source, a wave of jumping crickets is spread out in a fan shape and advances for some distance, until it finally dies out.

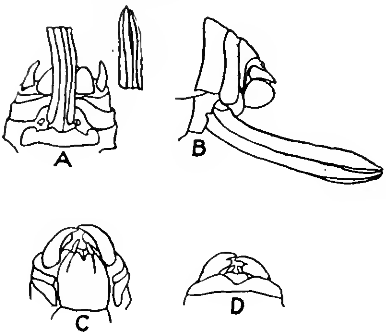

FIGURE 17.—Sixth instar of the Mormon cricket: A, Ventral view of ovipositor of female (in two parts); B, lateral view of same; C, ventral view of subgenital plate of male; D, dorsal view of same. Enlarged 4 diameters

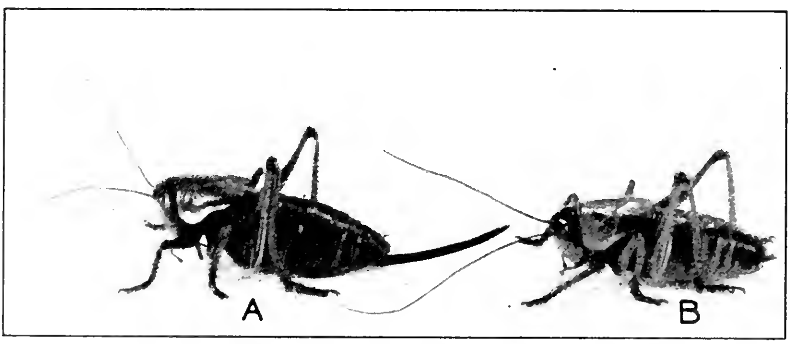

FIGURE 18.—Seventh instar of the Mormon cricket: A, Female; B, male. About natural size

Owing to the fact that Mormon crickets hatch at a much lower temperature than do grasshoppers, they usually make their appearance about a month earlier. In the first and second instars it is necessary for them to pass through the cold spells that usually occur in the early months of spring. Undoubtedly some die during this cold weather, but for the most part they survive, mainly because of their habit of congregating under dry cow manure, rocks, or whatever rubbish is available, until the cold spell has passed.

During the warmer weather the young crickets spend their days in the open, and at night seek cover in much the same way. About sundown the crickets gather in piles an inch or two deep and a foot or more across; somewhat later these clusters are broken up and the insects disappear under cover for the night. Early in the morning (providing it is daylight), when the temperature reaches about 40° F., they begin emerging from their night shelters and gather in small clusters until the sun is well above the horizon, when these clusters are again broken and the daily activities commence. It has been observed that a passing cloud, momentarily obscuring the sun, causes them immediately to form in clusters. A shower drives them to shelter, from which they emerge when it has passed, and again gather in clusters until they become warmed.

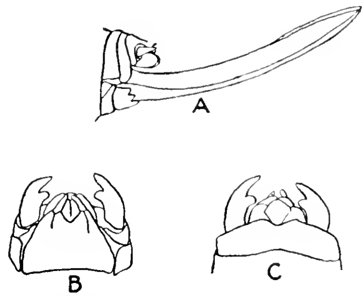

FIGURE 19.—Seventh instar of the Mormon cricket: A, Lateral view of ovipositor of female, × 2; B, ventral view of subgenital plate of male, × 4; C, dorsal view of same, × 4

These habits of clustering on the warm, bare spots, and seeking shelter during the night and inclement weather, are adhered to throughout the life of the cricket. The adult is not so likely as are the nymphal instars to seek shelter at night, but this fact may be due

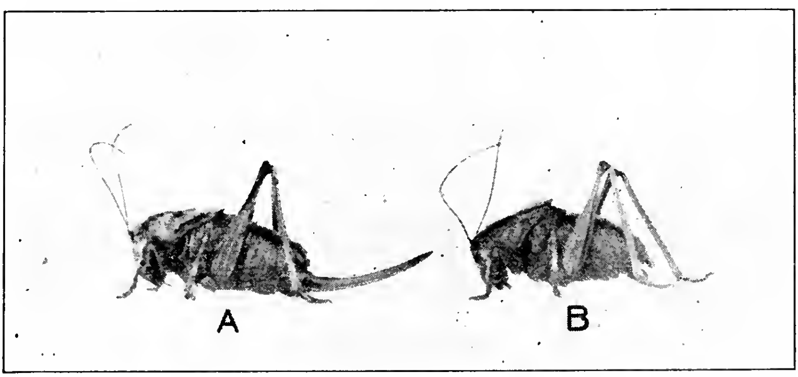

FIGURE 20.—Adult Mormon cricket: A, Female; B, male. Two-thirds natural size

to the higher temperatures that prevail after the final stage has been reached. They do, however, cluster at sundown, especially on fence and telephone posts and the sides of buildings. These clusters are sometimes broken later, and the migrating or feeding resumed.

High temperatures at the surface of the ground during the day drive the adults up on weeds, fences, and buildings. This usually occurs when the surface of the soil reaches a temperature of 100° F., or thereabouts. When the temperature falls they descend to the ground and continue their activities.

FOOD PLANTS

Among the uncultivated plants, the following, in order, are the most desired for food by the crickets in Montana:

Common name	Scientific name
Bitterroot	*Lewisia rediviva* Pursh.
Tumbling mustard	*Sisymbrium altissimum* L.
Common mustard	*Brassica arvensis* (L.) Ktze.
Hare's ear mustard	*Conringia orientalis* (L.) Dumont.
Dandelion	*Taraxacum officinale* Weber.
Prickly lettuce	*Lactuca scariola* L.
Russian thistle	*Salsola pestifer* A. Nels.

The bitterroot, which is very common in western Montana, is a specially favored food plant of the young crickets, probably because its leaves are thick and juicy, and because it makes its appearance early in the spring. Practically all the mustards, especially tumbling, or "Jim Hill" mustard, are highly favored early in the spring, and throughout the entire growth of the crickets are eaten more readily than any other native plants. The seeds seem to be considered a great delicacy by the adults, and the pods of practically every mustard plant in cricket territory are found to be stripped of them. Dandelion is also eaten readily in the spring, but not to so great an extent later in the summer. Russian thistles are eaten only when very young and tender.

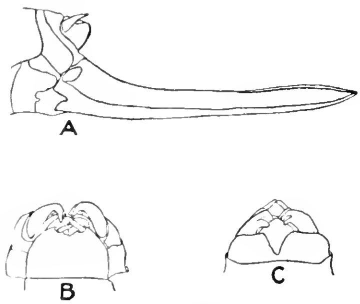

FIGURE 21.—Adult Mormon cricket: A, Lateral view of ovipositor of female; B, ventral view of subgenital plate of male; C, dorsal view of same. Enlarged about 2 diameters

To the foregoing list of uncultivated plants, Corkins (*3*) adds the following: Sagebrush, buck brush, scrub oak, willow tree, lupine, service berries, and miscellaneous wild legumes. Practically all of these plants except scrub oak occur in Montana, but crickets have never been observed eating them, possibly because other vegetation more to their liking was present.

There seems to be no limit to the variety of cultivated crops that crickets feed upon and damage. Garden crops of all kinds, fruits, including gooseberries, currants, and apples, and practically all field crops, are readily eaten.

CANNIBALISM

Throughout the entire life of the Mormon cricket cannibalism is a marked habit. Both in the field and in the laboratory the crickets have many times been observed feeding on one another, regardless of the abundance or scarcity of food. Scarcity of food may be an impetus to cannibalism but is not a necessary cause. In this habit there seems to be no discrimination between the sexes, since males have been observed feeding on females, and vice versa. Undoubtedly the females are more susceptible to attack than males, especially during the egg-laying period, since they may then become weakened and more easily fall a prey to their fellows. While laying eggs they must become fixed for a time in one spot, thus making themselves more liable to attack. Few crickets that are able to get out of the way are killed and eaten, but as soon as one becomes handicapped by the loss of a leg or by other injury it is immediately pounced upon and devoured. Great numbers are crushed when crossing highways where vehicles are passing. Their more fortunate fellows immediately gather to the feast, until the passage of a car or wagon through a band can be traced by the two black lines of cricket gathered to eat those that have been injured. Tales of crickets being so numerous on the roads as to force motorists to put chains on their cars in order to get through them may be highly exaggerated, but one can see how this might happen. The insects may keep accumulating in the wheel tracks, to be run over by oncoming cars until their crushed bodies form a slippery mass not unlike soft mud. Vague stories have been heard from time to time concerning this experience but have never been substantiated.

MIGRATIONS

The habit of migration has caused more conjecture and comment than any other habit of the Mormon cricket. For the last 75 years observers have been trying to determine why the insect migrates and what it is that influences the direction of migration. The opinion has been advanced by some that the crickets travel toward the sun; others have opined that they travel with the wind; and still others believe that they travel against the wind; however, of all the many theories that have been advanced not one holds true. Bands of crickets have been observed traveling toward the sun and, a half mile farther on, another band traveling exactly in the opposite direction or at right angles to it. In fact, it is entirely possible to find a series of bands of crickets "boxing the compass," traveling up hill and down, toward and away from cultivated crops, all in a single day and within the radius of a few miles. There seems to be no means of telling whether the crickets will travel east, west, north, or south. The fact remains that they do travel, en masse, usually in a straight line, and stop for nothing. What urges them to travel in a given direction and the reason why they travel at all are matters of sheer conjecture.

It has been possible to trace during a period of years infestations in a given direction for a given locality. In northwestern Colorado the infestation for the period from 1921 to 1927 has moved distinctly eastward. In western Montana the general direction of the migration during a period of three to five years has been toward the south. In Washakie and Big Horn Counties, Wyo., the general direction of migration has been toward the north. The reason why these directions were chosen is so far only a matter of guesswork, and probably years of intensive research would be needed before any definite conclusions could be reached, if an explanation could be found even then.

From the time the crickets hatch in the spring until they disappear in the fall they are almost constantly on the move, if weather conditions are favorable. They do not as a rule travel very far while in the first four instars, but move about apparently in search of food. The big migrations take place in the interval from the time they reach the fourth instar until their activities are over in the fall. During these migrations the rate of progress ranges fom one-eighth of a mile to 1¼ miles a day. Corkins (*2*) records one instance in which a band traveled 1¼ miles in one day. Johnson (*4*) records one in which it took a band of crickets one week to cover 5 miles, or about three-fourths of a mile a day. The distance traveled varies somewhat with the different stages, the crickets in the instances mentioned having been adults. Weather has a marked influence on the migrations, little or no travel taking place during wet, gloomy weather. They cease entirely when the temperature at the surface of the soil reaches approximately 100° F. Most of the moving is done by daylight, although the crickets have been observed traveling at night.

When a band begins moving it travels in a straight line and stops at nothing. If a board fence, a house, or other obstacle is encountered the crickets will try to climb over the top instead of going around. An instance is called to mind in which a band of these insects entered an open-air pavilion in a town in Wyoming where a dance was in progress. Their crushed bodies soon made the floor so slippery and nauseating that all the dancers had to stop and leave the place.

REPRODUCTION

Courting and mating usually take place from 10 days to 2 weeks after the crickets reach the adult stage, and occur in the forenoon between the hours of 8 and 12. The following description of the process written by Yothers (*8*) for *Peranabrus scabricollis* describes it very well for *Anabrus simplex*, and little can be added:

> If a male is confined with a female he courts her somewhat after the following manner: At about eight or ten o'clock, if the morning is fairly warm and bright, he begins to chirrup to the female, who does not seem to pay any attention to his advances, but as he continues to sing and side up to her, feeling antennae with her and trying to get beneath her, she gradually becomes less indifferent to his presence, yet shows almost no response to all his pleadings. She does not attempt to escape from him, but by gently but firmly pushing him away with her nearest foot, when he makes too ardent advances, she shows that she is not to be too easily won. Often she assumes a tantalizingly receptive attitude and the male attempts to connect, but after many trials—she remaining patiently still the while—he gives up and goes away. One pair was observed courting and attempting copulation for two and one-half hours before they finally separated without mating. In another case the pair had courted only a few minutes when the female advanced toward the male, walked over to him then stopped and waited while he caught hold of her with his hooked cerci. After a few seconds there were several throbbing pulsations of the male's abdomen, and the white seminal sac appeared and was passed to the female. The female pulled away at once then, turned the male over and tore the mass from him. The actual process of copulation lasts from three to ten minutes, after which the female goes about with her ovipositor well up off the ground so that the sticky mass will not become covered with particles of dirt and other rubbish. After a few minutes she may reach beneath herself and eat away a portion of the seminal sac, or her male consort or her other comrades may eat away some of it; but the greater part, and perhaps, under normal conditions, all of it, is absorbed into the bursa copulatrix. After an hour or so the mass has entirely disappeared.

Oviposition may take place at any time of the day, although the greater number of eggs are probably laid in the afternoon. When a female is ready to deposit eggs she walks around over the surface of the ground with the tip of the abdomen raised so that the ovipositor is in a vertical position. In this manner the soil is tested in several places until a satisfactory spot is found. The ovipositor is then worked into the soil by a shuttlelike movement of the right and left pairs of valves, brought about by muscular contractions of the abdomen, until it is inserted to the farthest depth obtainable. The egg is then passed down between the two outer pairs of valves, aided by the inner pair. As soon as the egg is placed in the soil the ovipositor is withdrawn and the entrance to the hole is covered with dirt by a few quick, backward movements of the ovipositor. The insect then moves on to another location, where the process is repeated.

There seems to be very little choice in the selection of a place for egg laying. Practically all types of soil are used, ranging from a hard-packed road to summer-fallowed wheatland, but apparently a firm, sandy soil is favored. A sunny location is usually chosen, with an eastern, western, or southern exposure. The northern exposures are for the most part ignored. Bare ground is usually preferred, but eggs have been collected in native grassland and in alfalfa fields, tucked in around the bases of the plants and even in the centers of the clumps.

The number of eggs laid by a single female in the field is undoubtedly quite variable. Of 15 females individually caged with mates at the field laboratory at Billings one laid as many as 160 eggs, and the average for the 15 was 85.5, the total for all being 1,283. As many as 35 eggs were laid by a single female in one day. The results of these experiments are summarized in Table 2. It was found that a female was able to lay eggs about once in every seven or eight days, from the time the first eggs were deposited until she died. Since several of the females used in the laboratory experiments died after laying only a few eggs, it seems probable that natural field conditions would aid the egg laying and bring the general average for the number of eggs for an individual nearer to 150 or 160.

TABLE 2.—*Record of eggs laid by 15 Mormon crickets, kept individually caged, with mates, at the field laboratory of the Bureau of Entomology at Billings, Mont., in the interval June 29 to August 6, 1927, inclusive*

Cricket No.	Number of eggs laid on consecutive days numbered—																																					Total
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	
1	4	0	9	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	31	0	0	0	0	0	0	0	0	0	0	0	0	0	11	(1)			61
2	20	0	13	1	0	8	15	0	9	0	0	27	0	0	0	0	0	1	0	1	0	0	(1)															95
3	16	0	15	0	7	12	7	0	(1)																													57
4	22	0	0	9	0	0	20	9	0	16	(1)																											67
5	19	13	0	3	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	15	0	1	0	0	(1)					57
6	40	0	4	10	12	0	0	0	0	0	24	39	0	0	0	0	0	6	8	8	0	0	0	0	0	0	0	0	1	0	0	0	0	0	5	(1)		160
7	5	17	0	0	11	0	0	0	0	4	0	0	1	0	0	0	0	0	0	22	0	0	0	0	11	0	0	0	0	6	(1)							77
8	25	0	7	0	31	8	2	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	3	0	3	1	(1)							85
9	12	0	0	31	0	0	21	0	0	13	0	0	9	0	0	0	1	(1)																				87
10	30	1	18	0	2	0	0	0	0	7	0	0	0	0	16	0	0	0	0	10	0	0	0	0	0	0	13	0	0	0	0	0	0	0	17	0	(1)	117
11	10	11	2	0	0	11	0	2	0	0	0	0	0	0	14	0	0	5	0	5	0	0	0	0	0	0	0	0	1	5	0	1	(1)					67
12	29	1	14	0	13	22	0	0	1	0	0	3	0	0	0	0	0	6	0	0	0	0	0	4	(1)													96
13	33	0	0	19	0	0	0	0	9	0	0	4	0	0	9	0	4	1	(1)																			79
14	19	0	8	0	15	0	5	0	6	0	0	0	0	0	0	0	0	0	0	13	0	0	0	0	0	0	0	2	0	0	1	0	0	0	0	0	(1)	69
15	19	0	35	0	7	29	0	0	1	0	0	2	0	0	0	0	0	16	0	0	(1)																	109

[1] Died.

Table 2 presents the record of each of the 15 female crickets for each consecutive day from and including the day of her first oviposition to and including the day of her death, the actual dates not being given. For instance, under "2" in the box heads is shown the record of each cricket for the day after that of her first oviposition. The dates of first oviposition ranged from June 29 to July 4.

NATURAL CONTROL

PREDATORY ENEMIES

The Mormon cricket, being large and clumsy and not capable of flight, easily falls a prey to many predatory enemies. Of these the birds are the most important. Every band of crickets is marked by a following of crows, blackbirds, or robins; crows seem especially fond of this insect and gather in groups of from 10 to 50 to feed upon it. The following list of birds will give an idea of the great variety of enemies of this insect:

Common name	Scientific name
California gull	*Larus californicus.*
Franklin's gull	*Larus pipixcan.*
American bittern	*Botaurus lentiginosus.*
Richardson's grouse	*Dendragapus obscurus richardsoni.*
White-tailed ptarmigan	*Lagopus leucurus.*
Sharp-tailed grouse	*Pedioecetes phasianellus columbianus.*
Sage grouse	*Centrocercus urophasianus.*
Swainson's hawk	*Buteo swainsoni.*
American sparrow hawk	*Cerchneis sparveria.*
Horned lark	*Otocoris alpestris* subsp.
American magpie	*Pica pica hudsonia.*
Mexican raven	*Corvus corax sinuatus.*
Common crow	*Corvus brachyrhynchos brachyrhynchos.*
Western crow	*Corvus brachyrhynchos hesperis.*
Pinyon jay	*Cyanocephalus cyanocephalus.*
Western meadowlark	*Sturnella neglecta.*
Brewer's blackbird	*Euphagus cyanocephalus.*
Lark bunting	*Calamospiza melanocorys.*
Western robin	*Turdus migratorius propinquus.*

To this list of wild birds may be added all kinds of domestic fowls, chickens and turkeys being the most important.

The cricket has proved to be a very good food for chickens and turkeys. The bodies of crickets, although composed largely of water, are rich in protein. Large bands of turkeys have subsisted almost entirely on crickets until fattening time in the fall and, among all of them, only one turkey was ever observed to have become "crop bound." The only other undesirable result of this diet was an occasional case of diarrhea. It may be remarked that a very high percentage of the turkeys from "cricket country" were graded No. 1 when placed on the market. A pure diet of crickets seems to be all right for growing chickens, but is not so desirable for laying hens. It has many times been observed that hen's eggs from territory infested with crickets have dark-colored yolks, and have come to be known to the produce buyers as "cricket eggs." This discoloration of the yolk of course makes the eggs very undesirable to the housewife, and consequently eggs from territory infested by crickets are for the most part avoided by the buyers.

Among the other predators, rodents, including several species of gophers, ground squirrels, and marmots, are fond of Mormon crickets. Coyotes, skunks, and badgers undoubtedly eat great numbers of this insect, but of course the actual value of any of these animals as a means of control is problematical.

On the authority of F. W. Boyd, who did extensive work with the cricket in Wyoming in 1922, 1923, and 1924, sheep might be added to this list of predators. In his field notes he has recorded several observations of sheep which have been seen eating them as a repast, with apparent enjoyment. No observations of this kind have been made, aside from those made by Mr. Boyd, as the cricket has required very little attention in Wyoming since 1924, and conditions favorable to such a phenomenon have not been found elsewhere.

INSECT PARASITES

Parasites of the Mormon cricket are very limited in numbers, perhaps largely because the crickets are extremely cannibalistic. It is

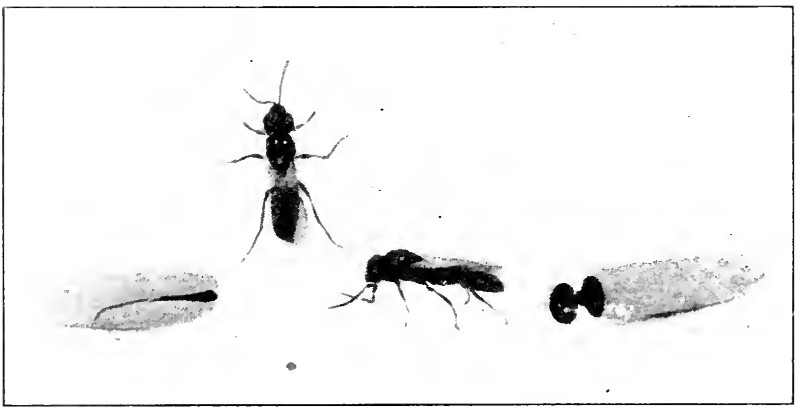

FIGURE 22.—*Sparaison pilosum*, an egg parasite of the Mormon cricket. A parasite has emerged from the pupa case on the right. The empty case is shown with the lid open. Enlarged about 4 diameters

easy to see how a cricket infested with some internal parasite would, on becoming weakened, fall a prey to the more fortunate crickets and be devoured. Not only would the infested cricket be destroyed but the parasite as well. There are, however, one parasite and a predator known that may be considered as somewhat helpful in controlling this insect. *Sparaison pilosum* Ashm., a hymenopterous insect, is a parasite of the eggs of Anabrus (fig. 22), as has been recognized for some time by entomologists, but its actual value as a control has never been considered great. Observations in western Montana have shown, however, that it is a factor not to be overlooked. In 1926 a very high percentage of the eggs laid in the Charlo district in Lake County, one of the worst infested places in 1925 and 1926, were parasitized. In this district in 1927 very few crickets hatched, and little or no control work was necessary. Other districts in Lake County were not so fortunate, although parasitism ranged as high as 50 per cent in the vicinity of Round Butte, and the control work was noticeably less in 1927. Eggs collected from all parts of the infested territory in the fall of that year show a very high percentage of parasitism.

This parasite lays its eggs inside the cricket egg, probably after the latter is deposited. Within a month or six weeks after the parasitized eggs have been laid they can be distinguished from those that contain cricket embryos. Parasitized eggs do not increase in size after they are deposited, whereas those not parasitized develop normally and noticeably increase in size. The parasite apparently develops only at a high temperature, and therefore undergoes little or no development in the fall. Practically all its development takes place in late spring and early summer, and it is ready to emerge about the time egg laying begins.

The other known insect enemy, the wasp *Palmodes laeviventris* Cress.,[5] is predatory and was observed for the first time attacking Anabrus in western Montana in the spring of 1927, by the State men in charge of the control campaign. Through the summer great numbers of this insect could be observed busily digging their burrows and burying crickets. Their exact procedure, if any is followed, is not known. It has been observed, however, that the wasp stings its victim several times, if necessary, paralyzing the cricket and rendering it helpless, but does not cause its death. The cricket is then dragged into the wasp's burrow, which may or may not have been previously dug, and the egg of the wasp is attached to the membranous tissue in the cricket's side, near the hind leg. When the young wasp hatches it remains where the egg was attached and begins to feed. When it has attained its full growth pupation takes place without any change of position, as is evident from pupa cases dug from the soil still attached to the remaining pieces of the cricket, which served as its food. Although it is reported that as many as five pupa cases have been taken from one burrow, the usual number in a burrow is two.

Little can be said as to the value of this predatory wasp in controlling the Mormon cricket, inasmuch as 1927 was the first year in which it was observed in large numbers on this particular insect. Further work on its habits and life history is necessary before any definite statement on this point can be made, but it is highly probable that if this insect were plentiful enough it would be a decided factor in the control of the Mormon cricket.

ARTIFICIAL CONTROL

BRAN MASH

Experiments have been carried on for years with bran mash in order that an effective method of controlling the Mormon cricket might be found. Although some good results have been obtained, more especially with crickets in the younger stages, it is believed that poisoned-bran mash is not a reliable means of control. The insects are very erratic in their feeding, and whereas good results may be obtained one day, poor results may be found the next. Then, too, since the insects are almost constantly in motion, it is very diffi-

[5] Determined by Nathan Banks.

cult to see the actual results, and in the case of the average farmer "seeing is believing."

After much experimentation the following bran bait has given the best results, but even with this one the results have at times been very mediocre:

Bran	100 pounds.
Amyl acetate	3 ounces.
Salt	5 pounds.
Liquid sodium arsenite	8 pounds (3 to 4 quarts).
Water	11 gallons.

BARRIERS

Mechanical control by means of barriers is completely effective in stopping migrations of the Mormon cricket and in destroying the insects themselves. These barriers consist of objects over which the insects can not climb, and must have pits dug at intervals along their sides to trap the crickets encountering them. The main objections to these barriers are the cost, the difficulty with which they are handled, and the attention required for their operation. Several types of barriers have been tried out, and all have been fairly successful. A sheet-metal barrier now in use in Colorado is perhaps the best, but it is also the most expensive. It consists of a 10-inch strip of galvanized iron, and the material costs from 5 to 10 cents per foot, or approximately $265 to $500 per mile. The barrier used in Washington against the Coulee cricket is very good; it consists of an 8-inch board set on edge, with a 4-inch strip of tin nailed on the top, projecting outward at right angles from the board toward the direction from which the insects approach. Where such a barrier can be constructed to extend across a ditch full of water (fig. 24) it becomes very effective. This barrier should cost in the neighborhood of $250 per mile, the expense depending upon the cost of lumber in any particular region. It is very effective, but requires more attention than the sheet-metal barrier, and is harder to transport and set up.

The least expensive type of barrier is one devised by a farmer in western Montana. It consists of a board 8 inches wide set at an angle of 45° or 50° above the ground, and having a 3-inch strip of oilcloth fastened to the inner side near the top by means of a paste made of flour and water. (Fig. 23.) The cost of this barrier should not exceed $150 per mile. It is effective, but requires constant attention and, like the board-and-tin barrier, is hard to transport and to set up.

It is believed by many that all of the barriers that have been tried are too expensive to use in actual control work. They are, however, very useful in stopping migrating bands when the depth of the band is much greater than the width. A barrier was used quite effectively in Washington against the Coulee cricket (5), and this method of control has also been used in Colorado and Utah. Five miles of the all-metal barrier were constructed in Routt County, Colo., in the summer of 1927, and the device was instrumental in stopping migratory bands of the Mormon cricket before any very serious damage was done.

ARSENITES

Owing to the fact that poisoned bait has not under all conditions been found efficient in control of the Mormon cricket, and since

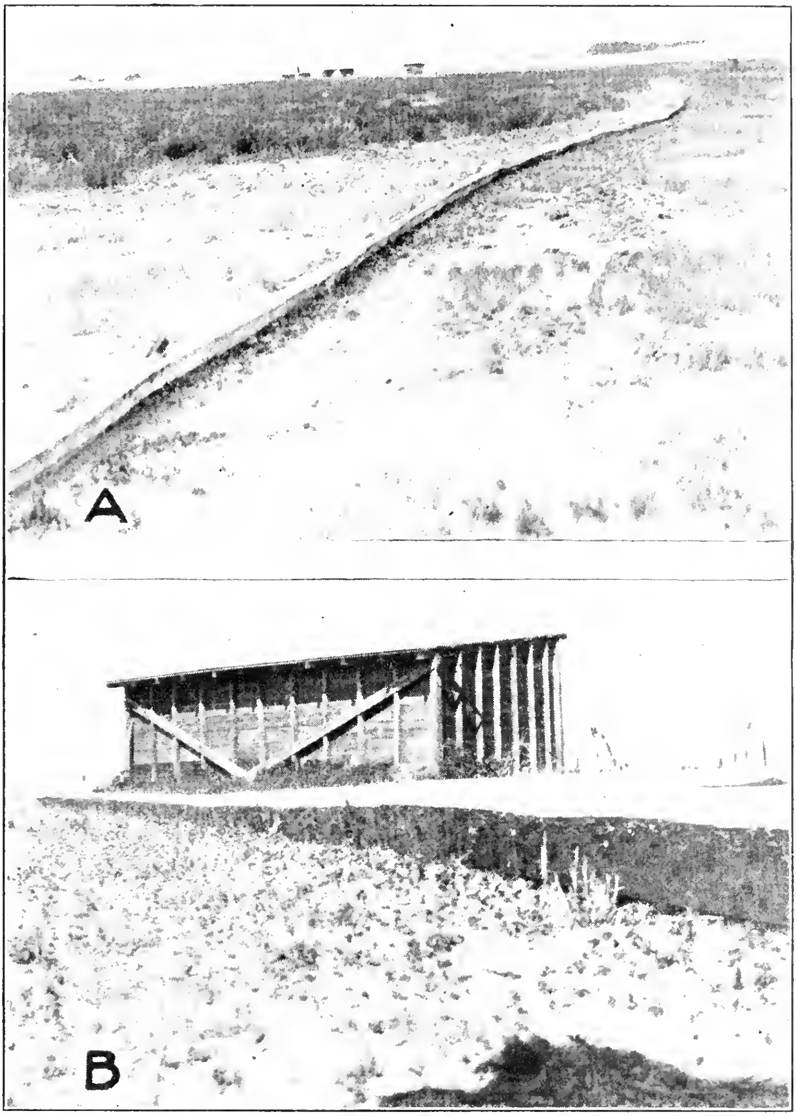

FIGURE 23.—A. A barrier made of an 8-inch board, to which is attached a strip of oilcloth 3 inches wide; B, a nearer view of the same barrier with crickets massed in front of it

barriers are expensive and hard to handle, a need for a better method of control has been felt. Experiments have accordingly been carried out with various dusting and spraying materials which appeared suitable for killing the insects by direct or indirect contact. Of all the materials tested, powdered arsenites of sodium and calcium proved the most effective. Either of these materials, mixed with hydrated lime in the proper proportions and dusted over the swarms, is very effective against this insect in almost any stage of its development.

This method of control was used almost exclusively in the campaign in western Montana in 1927, both arsenites being employed, and was so effective that the loss to crops from the cricket was less than 10 per cent in an area that suffered loss of 100 per cent in 1926. The sodium arsenite was used in the proportion of 1 pound of arsenite to 4 pounds of hydrated lime, and was applied at the rate of 5 pounds of the dust per acre; the calcium arsenite was less diluted, there being 1 pound of the arsenite to 3 pounds of hydrated lime, and 8 pounds of the dust was used per acre. The powder was applied with dust guns, directly on the swarms of insects. Results could be seen in from 12 to 24 hours after the application and the mortality among the crickets at the end of a 4-day period ranged from 75 to 100 per cent. Although results from these insecticides were excellent in western Montana in 1927, it is believed that further experience with them is necessary, particularly in other localities, before any definite statements can be made regarding the use of arsenites for controlling the Mormon cricket.

FIGURE 24.—A very effective "water trap" used against the Mormon cricket in some irrigated districts

SUMMARY

The Mormon cricket is essentially an insect of the mountains, although it is known to be present in many of the States occupying the Great Plains, and its habitat extends across the United States, from Texas to Minnesota. It is not really a cricket, but is a wingless, long-horned grasshopper. It naturally inhabits high, rugged hills in mountainous country, from which it migrates from time to time into cultivated valleys, to cause damage to crops. From 1848 to the present time it has been known as a serious pest to agriculture, sometimes causing losses amounting to thousands of dollars, and seriously reducing the number of farms under cultivation.

The crickets usually occur in bands varying in extent from the area of a city block to a square mile or more. The bands are very dense, there being often from 100 to 500 to the square foot. In general, cereals are injured by them more than are other crops. Alfalfa, garden crops, and small fruits are severely attacked.

The Mormon cricket reaches the adult stage early in the summer, and its eggs are laid in the summer and early in the fall and hatch in the following spring.

Between the stages of the egg and the adult are 7 nymphal stages, in all lasting from 75 to 90 days. When hatched from the egg and after each molt the insect is light tan in color; on exposure to the air it soon turns black in the first three instars, but with some variation in color in the remaining four. Although the insect is wingless, rudimentary wings develop and become visible in the seventh instar and in the adult. The development of the posterior organs has been especially observed from instar to instar, in particular the cerci, the claspers, the subgenital plate of the male, and the ovipositor of the female, until it is completed at the time the adult emerges from the seventh molt.

The adult stage is attained in the early part of the summer, usually between the middle of June and the middle of July. At the age of 10 days or 2 weeks the female begins egg laying, which is continued to the end of summer or early in the fall. The duration of the life of the adult seems to be not well understood. The insect is hardy and frequently makes good use of shelter as a protection against cold and inclement weather, but reducing the likelihood of longevity are its pronounced cannibalistic habit and a great number of predatory enemies.

The food of the Mormon cricket includes a considerable number of uncultivated plants, bitterroot and several kinds of mustard being especially favored, and practically all kinds of field and garden crops. The fondness of this insect for nearly everything in the way of plant life grown by the farmer is the cause of its great economic importance as a pest.

From the time the crickets hatch in the spring until they disappear in the fall they are almost continually in motion when the weather is favorable. The migrations of their bands, apparently in search of food, depend somewhat upon the weather and vary greatly in speed. A band, once under way, travels in a straight line and stops at nothing. The cause of their choice of any particular direction has always remained a mystery.

Mating occurs 10 days to 2 weeks after the adult stage is reached, and oviposition follows shortly afterwards. Eggs are laid at any time in the day, probably more especially in the afternoon, and in any kind of soil. The number laid by one female varies greatly, but the rate of oviposition in the field is not well known.

Notwithstanding the hardiness and activity of the Mormon cricket, it is large and clumsy and incapable of flight, and suffers from the ravages of many predatory enemies, wild birds being the most important. Domestic fowls consume great numbers of the crickets and find them a very good food. Various rodents, such as gophers and ground squirrels, are fond of them. Besides these and other animals, sheep have been known to eat them freely.

Among insect enemies of the cricket are one hymenopterous insect, *Sparaison pilosum* Ashm., which parasitizes the eggs of the cricket, preventing their development, and a predatory wasp, *Palm-*

odes laeviventris, which stings crickets, paralyzing them, and drags them to its burrow, where they later serve as food for the young of the wasp. The economic value of these insects in controlling the cricket is as yet not well determined.

Artificial control by means of poisoned bait has not been found reliable, although some good results have been obtained with a poisoned bran mash. Encouraging results have been obtained from experiments with powdered arsenites of sodium and calcium, mixed in proper proportions with hydrated lime and dusted over the swarms. Mechanical control by artificial barriers is completely effective in stopping migrations of the cricket and in destroying the insects themselves, but they are expensive and difficult to handle. Several types of barrier have been tried and found successful. They were constructed of various materials, such as metal, metal and wood, and wood and oilcloth.

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AGRICULTURAL SURVEY OF EUROPE

HUNGARY

BY

LOUIS G. MICHAEL

Principal Agricultural Economist, Bureau of Agricultural Economics

United States Department of Agriculture, Washington, D. C.

AGRICULTURAL SURVEYS OF FOREIGN COUNTRIES

The bulletins of the agricultural surveys of foreign countries contain an analysis of the agricultural situation in each country, studied from the viewpoint of the potential demand for agricultural products by those countries whose production is not sufficient to meet their national requirements, as well as the nature and extent of the competition from foreign producers that the farmers of America must meet in disposing of their surplus in foreign markets. These surveys include a comparison between the pre-war and post-war trends in agriculture as affected by the economic conditions, territorial changes, if any, and other factors in each country, brought about by the World War. Beginning with this bulletin the surveys will include analyses of the relationships of production to disappearance and export or import, which form the basis for forecasting the probable exportable surpluses of competing countries and the import requirements of customer countries.

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Agricultural Survey of Europe: Switzerland (Tech. Bul. 101).

Agricultural Survey of Europe: The Danube Basin—Part 2 (Tech. Bul. 126).

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UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

AGRICULTURAL SURVEY OF EUROPE: HUNGARY

By LOUIS G. MICHAEL
Principal Agricultural Economist, Bureau of Agricultural Economics [1]

CONTENTS

HUNGARY AND THE UNITED STATES

Hungary is competing with the United States in Austria and Czechoslovakia on the wheat and flour markets and can become a very considerable competitor as regards pork, lard, and other pork products on the markets of central Europe. The future exportable surpluses of rye, barley, corn, and oats will probably be smaller than before the World War on account of larger domestic use as feeding stuffs in the livestock industries. Hungarian sugar will not in all probability become an important factor in western European markets. It is improbable that the American tobacco situation will be affected, in even a slight degree, by Hungarian demand, as Hungary has in the past utilized very little tobacco grown in the United States. On the other hand, an expanding textile industry will probably absorb increasing quantities of American-grown cotton.

[1] With the collaboration of Susie White, Bureau of Agricultural Economics.

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THE PEACE TREATY AND HUNGARIAN TRADE

Before the World War, the old Kingdom of Hungary possessed a variety of industries that had reached a relatively high grade of development (*5*).[2] After the war, the territories constituting residual Hungary had shrunk to about one-third the size of the former Kingdom. The industries found within this restricted territory continued to develop along the lines that had marked the industrial development of the old régime. Certain lines of endeavor, as the flour-milling industry, fell into a state of stagnation, and some of the milling plants were transformed to meet the requirements of other lines of manufacture.

In pre-war times, the old Kingdom of Hungary controlled its own sources of food products and raw materials, with the exception of cotton. The old Kingdom, with 20,000,000 population, constituted a common-duty territory with the former Austrian Empire, whose population was more than 31,000,000. The agricultural industry of the eastern and southern parts of the Dual Monarchy and the industrial and commercial interests of the west and north enjoyed perfectly free internal trade and protection against the products of outside States. This situation was, in some respects, advantageous to Hungary. A market for practically the whole of the agricultural surplus of the old Kingdom was assured within the former Austrian Empire and, as a rule, Hungarian sellers were not compelled to seek customers beyond the frontiers of the monarchy.

On the other hand, on account of the close association with Austria, the basic industries of Hungary were not developed to a degree commensurate with its raw-material supplies. It had been the policy of the former monarchy to keep Hungary at the level of a raw-material producing country and to concentrate industrial production in Austrian and Czech centers. However, certain industries deeply rooted in agriculture or in forestry, inevitably did develop—such as the milling industry (after Minneapolis, Budapest had the greatest flour mills in the world), the sugar industry, the manufacture of alcohol, beer, starch, salame sausage, vegetable oils, commercial fertilizers, the products of wood distillation, cellulose, and tannin. It was an ancient endeavor of the country to employ a considerable part of the wool crop for the manufacture of cloth, with which to satisfy the demands of its own agrarian population.

As a consequence of the peace treaty, the conditions and prospects of production in Hungary have undergone a material and critical change. Surpluses of all the principal agricultural products of present-day Hungary are dependent for a market on the export trade. Wheat, rye, barley, oats, corn, livestock and meat, potatoes, eggs, vegetables, oilseeds—all alike must be exported for the most part in considerable quantities. Although there is a near-by demand for these materials—at a price—there has developed since the World War, even in States preponderantly industrial in character, a tendency to develop their own agricultural resources—to become as nearly as may be independent of outside sources of supply. As a consequence, the sale of agricultural materials in foreign countries encounters ever-increasing difficulties. It is the tendency of western States, as Austria, Czechoslovakia, and Germany, to force by energetic methods

[2] Italic numbers in parentheses refer to "Literature cited," p. 104.

a free path for their manufactured products and at the time to build up their economic status by employing as far as possible the products of their own agriculture.

Hungarian corn for feeding livestock can find a market here and there in the feed lots of lower Austria and Bohemia, but Hungarian flour is faced with obstacles almost insurmountable. The powerful competition of American flour and lard is keenly felt by Hungarian farmers. In 1913 there were 13 flour mills in Budapest with a daily capacity of 338 carloads [3] of wheat and 79 carloads of other grain. In 1925 only 10 mills with a daily capacity of 300 carloads of wheat worked 20 per cent of their capacity. It is reported that some of these mills have been dismantled as to their milling machinery, and are being fitted with spindles and looms.

The general situation in Hungary may be outlined as follows.

THE AGRICULTURAL SITUATION IN HUNGARY

Hungary, like each of the succession States, has passed through a crisis that has strained national resources to the breaking point. However, the season of 1927 found the worst of Hungary's troubles forced into the background. Its position on the world's money market was improved. The land value of residual Hungary (the portion of the great plains east of the Danube, the Alföld, and the western highlands now comprised within the present frontiers of the country) was estimated at 6,000,000,000 gold crowns or about $1,215,600,000 [4] and there was a national inventory amounting to about 2,000,000,000 additional gold crowns or $405,200,000.[4] The American people have become richer and the Hungarians poorer since the World War; but for this very reason production of farm crops and animal products in Hungary is cheaper than in the United States and the surplus-producing areas of this whole region are in close conjunction with the markets in which American farmers must meet their competition.

Before the World War (1913), it was possible to market American wheat in Liverpool 11 per cent (*9*) cheaper than the Hungarian farmer could sell his wheat in Budapest. In 1925, Hungarian wheat in Budapest was 8 per cent cheaper than was overseas wheat of similar quality in Liverpool. On the other hand, in spite of a lower standard of living in the countries to the south, the cost of agricultural production in Hungary is relatively less than that in the neighboring Balkan countries because the handling of the soil and animals in southeastern Europe is less scientifically systematic than in Hungary. At the close of 1926, the prices of cattle and swine in Rumania and Yugoslavia were higher than in Hungary. Yields per acre in Hungary average higher than in the southeast and in the best years approach average German standards.

In 1926, Hungarian industries produced wares valued at 1,698,000,000 gold crowns or $344,014,800, in the manufacture of which domestic and foreign raw materials to the value of 900,000,000 gold crowns or $182,340,000 were utilized. On the other hand, the land and the farmers of Hungary produced farm crops, animals, and animal products to the value of 1,800,000,000 gold crowns or $364,680,000.

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[3] A carload is 10 metric tons or 22,046 pounds. [4] The value of the gold crown was 20.26 cents.

The territories comprising the present Hungarian State, occupying the rolling country west of the Danube and the great plains region east of the Danube, the Alföld, have almost no natural resources other than the products of their agriculture. Nearly the entire industry and commerce of the former Kingdom of Hungary [5] was

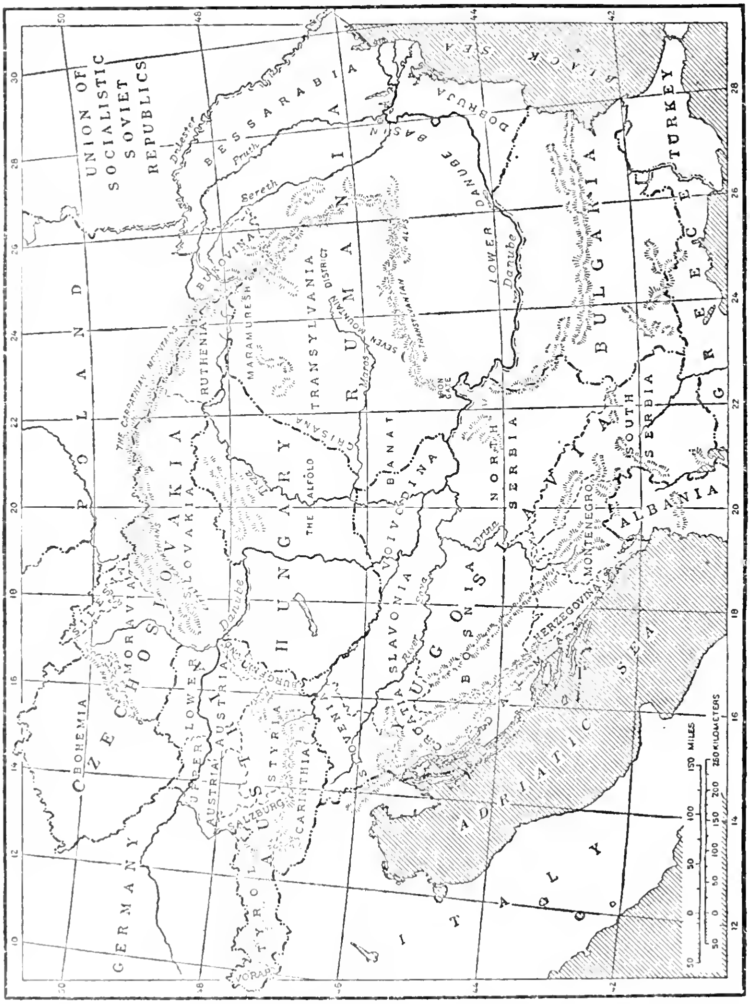

FIGURE 1.—MAP OF THE DANUBE BASIN

Hungary is the residual part of the old Kingdom of Hungary after segregating the territories of Slovakia, Ruthenia, Maramuresh, Crisana, Seven Mountains, Banat, Voivodina, and Burgenland to neighboring States.

founded upon the manufacture of and trade in commodities whose raw materials were the products of its own agriculture. More than half of these agricultural products originated in the outlying regions of the old Kingdom which after the World War, were segregated from

[5] In 1913, total exports from the old Kingdom of Hungary were valued at $380,400,000, of which manufactured and semiprocessed goods were valued at $183,200,000. Raw materials were valued at $197,200,000. The most important products of agricultural origin were flour, $51,200,000; cattle and hogs, $46,200,000; wheat, $22,800,000; and barley and corn $15,000,000 (Wilgress (*16*)).

residual Hungary by the treaty of Trianon [6] and were ceded to one or another of the succession States, which were created out of units of the former Austro-Hungarian Monarchy.

The industrial and commercial machinery for handling the surplus raw materials produced in the territories that comprised the old Kingdom of Hungary (that is, (1) in the present residual State of Hungary; (2) in Croatia, Slavonia and Voivodina, ceded to Yugoslavia; (3) in eastern Banat, Crisana, southern Maramuresh and the Seven Mountain region, ceded to Rumania; (4) in Slovakia and Ruthenia, ceded to Czechoslovakia; and (5) in Burgenland, ceded to Austria) was centralized for the most part in Budapest. For this reason, when residual Hungary began its career as a separate, isolated State, it was burdened with an enormous "overhead" of mills that had been cut off on the one hand from their former sources of wheat and other grains to be ground and on the other from the former markets in which they had been accustomed to sell their flour.

There were banks without funds or official affiliations with their branches in former outlying regions. There was an army of merchants whose occupation had been to assemble products from the surplus regions to the east and south and arrange for their transport and disposition in the deficit regions of the north and west. The former Austria-Hungarian Monarchy had been a well-balanced, nearly self-sufficient economic unit. At the beginning of the postwar reconstruction period, these merchants found themselves almost without transportation facilities with which to handle even the small fraction of the former quantities of agricultural products that were available for commerce. The economic existence of the residual Hungarian State is dependent upon the development of a highly intensive agriculture, producing surpluses of field crops and animal products within its own frontiers for export and upon the importation of raw materials or semimanufactured agricultural products for final processing by its mills and factories and the exportation of these in finished form.

The problems of an agricultural State, like Hungary, are totally different from those of an industrial region like northwestern Czechoslovakia or a commercial State like Austria. An agricultural State has the advantage that it can subsist under the most straitened circumstances without impairing its international credit through costly importations of food, as was the case with the Republic of Austria. On the other hand, it must depend upon the products of its soil to build up its international credit because it has no large surplus of manufactured goods (cotton, glass, iron, etc.) to send abroad as is the case with Czechoslovakia.

Thus, at the outset of its restricted existence, residual Hungary, although passing through very nearly as catastrophical a period of currency depression as residual Austria, was nevertheless able to subsist upon the products of its own soil and to survive the succession of crises of the past few years.

The struggle of Hungarian agriculture during the first few years following the World War has been that of adjustment to the burdensome conditions of heavy taxation and lack of credit at home and the

[6] For a discussion of the changes in boundary following the treaty of Trianon upon the agricultural situation in Hungary see (*10, p. 9–43*).

difficulty of finding favorable markets abroad. The situation, broadly speaking, is that Hungary, an essentially agricultural country, must endeavor to secure markets for its agricultural products by opening its doors to manufactured articles from abroad. On the other hand, highly industrialized countries, such as Germany, Austria, and Czechoslovakia, the most important markets from the Hungarian point of view, are naturally reluctant to throw down the barriers which protect their own agricultural interests, since the Hungarian market for their manufactures is too insignificant to outweigh the disadvantages involved in opening their markets to Hungarian wheat, flour, pork, beef, sausages, and lard. It is not so much Hungarian competition that they fear as that of Canada, Argentina, the United States, and even a resuscitated Russia, against which countries they could not consistently close their frontiers once they had opened them to Hungary.

By 1926, Hungarian agriculture, in spite of all handicaps, had recovered its pre-war averages as regards rye, corn, potatoes, and sugar beets, as indicated in Table 1. However, there are some indicative shifts in the relative manner in which the various cereals were seeded in 1926 as compared with the pre-war manner of seeding.

TABLE 1.—*Cereals, potatoes, and sugar beets: Average acreage seeded in present Hungary, 1909–1913 and in 1926, and acreage sown by large and small holdings during 1926*

Crop	Total acreage sown in—[1]				Holdings in 1926 of 100 Jochs (142.2 acres) or more [2]		Holdings in 1926 of less than 100 Jochs (142.2 acres) [2]	
	Average 1909–1913		1926		Acreage sown	Percentage	Acreage sown	Percentage
	1,000 acres	*Per cent*	*1,000 acres*	*Per cent*	*1,000 acres*	*Per cent*	*1,000 acres*	*Per cent*
Wheat	3,712	38.3	3,706	37.8	1,126	35.3	2,535	38.3
Rye	1,608	16.6	1,729	17.7	533	16.7	1,190	18.0
Total	5,320	54.9	5,435	55.5	1,659	52.0	3,725	56.3
Barley	1,322	13.7	1,050	10.7	419	13.2	684	10.3
Oats	849	8.8	679	6.9	334	10.5	355	5.4
Corn	2,192	22.6	2,631	26.9	775	24.3	1,854	28.0
Total 5 cereals	9,683	100.0	9,795	100.0	3,187	100.0	6,618	100.0
Potatoes	619		619		181		411	
Sugar beets	131		156		139		17	

[1] Total acreages were taken from succeeding tables which show the latest available figures for 1926. These figures will not check in all cases with the sum of the figures for separate holdings which are preliminary and were taken from a different source.
[2] From (9, p. 141).

The outstanding shift in relative cereal acreage occurs in corn, which by 1926 had increased 439,000 acres over the pre-war average. The next important change is in rye, which shows an increase of 121,000 acres. As will be shown later, not only has rye production increased somewhat, but there has been a positive increase in rye consumption, more than offsetting the decrease in wheat disappearance.

There was a small decrease in wheat of 6,000 acres in 1926, but in 1927 wheat acreage was 309,000 acres above the pre-war average. In 1926, barley and oats had fallen off appreciably—272,000 acres in the case of the former and 170,000 acres in the case of the latter cereal—with a further decrease in 1927.

On the whole, the acreage of the five chief cereals had increased; but the rates at which corn and rye were seeded indicate an increased influence of peasant agriculture following the Hungarian land reform in which greater areas are devoted to the production of human food and feed for hogs and cattle to be consumed on the farm. The decreased seeding of barley and oats indicates a decreased influence of large-estate agriculture, in which wheat and barley were grown extensively as cash crops and oats as feed for horses, whose breeding was a well-established industry among the landed nobility.

It will be noted that 71 per cent of the potato acreage was planted by the peasants in 1926; whereas the estates planted 89 per cent of the sugar-beet area.

These shifts in areas seeded have not affected the general utilization of land.

UTILIZATION OF LAND

The area of residual Hungary in 1927 was placed at 22,970,000 acres, of which 93.8 per cent was classified as productive land. Of this productive land, 60.3 per cent was under plow, 18.1 per cent meadows and pastures, and 11.7 per cent forests. A small acreage was devoted to gardens and vineyards. (Table 2.)

TABLE 2.—*Utilization of land in Hungary, present boundary, 1911, 1921, and 1927*

Utilization of land	1911 [1]		1921 [1]		1927 [2]	
	Acreage	Percentage of total acreage	Acreage	Percentage of total acreage	Acreage	Percentage of total acreage
	1,000 acres	*Per cent*	*1,000 acres*	*Per cent*	*1,000 acres*	*Per cent*
Plowlands	13,351	58.2	13,784	60.1	13,837	60.3
Meadows	1,706	7.4	1,646	7.2	1,657	7.2
Pastures	2,523	11.0	2,501	10.9	2,497	10.9
Gardens	216	1.1	246	1.1	252	1.1
Vineyards	499	2.2	539	2.4	534	2.3
Forests	3,094	13.5	2,714	11.8	2,695	11.7
Reeds	81	.4	69	.3	73	.3
Unproductive	1,422	6.2	1,422	6.2	1,425	6.2
Total	22,922	100.0	22,921	100.0	22,970	100.0

[1] U. S. Dept. Agr. Bul. 1234 (*10, p. 8*).
[2] Die Landwirtschaftliche Produktion der Welt in Jahre 1927 (*6, p. 355*).

Hungary is outstandingly a country devoted to field-crop production and the livestock industry. Wine making is also an important industry though restricted in scope.

THE MAGYAR PEOPLE

In the sixth century, Attila, the "scourge of God," raided Europe, was defeated, and his shattered hordes drifted back over the Carpathian Mountains toward Asia. Some 300 years later the vanguards of a similar people, the Magyars, under seven great princes seeped through the mountain passes into the forests of Seven Mountains (now part of Transylvania). When Kaiser Arnull invited these Magyar princes to aid him against the Moravians, who were crowding his people, the Germans, up into the Alps, he opened the way for this steppe people, weary of their sojourn in the mountains, to appropriate a new fatherland admirably suited to their needs. This was in the year 896.

Originating in the steppe countries north of the Caucasus Mountains, these closely related peoples, called Magyars, had for centuries drifted across the steppes of southern Russia and up into the Carpathians at last to find a resting place on the Alföld—the lowland plains or steppes of the Danube basin. They found the land sparsely inhabited by herders of cattle and tenders of sheep living in mud huts. The Magyars pitched their tents and appropriated the best of the pastures and meadows for their own wiry horses, their enormously long-horned cattle, and their long-haired milk sheep.

They had brought with them Slavic slaves whom they set to tilling the soil and herding cattle and sheep. The care of the swine was woman's work. The men occupied themselves only with the breeding and care of the horses and those pursuits that fitted them for battle. When they arrived, the Magyars found Slavic tribes scattered over the plain, as well as Teutons, Avars, Goths, and perhaps some remnants of the aboriginal Celts. The Serbs, Croats, and Slovenes were driven into the highlands to the south, the Germans into the foothills of the Alps, the Czechs, Slovaks, and Ruthenians into the foothills of the Carpathians, and the Rumanians into the Transylvanian Mountains. The other peoples, having no place to which to retreat, remained to be absorbed.

The princes and the warriors proceeded to war until, as the centuries passed, the flaming spirit to battle became more and more feeble and it became more and more difficult to muster raiding parties just for the love of raiding. The clusters of mud huts took on more permanent form, whose architecture was borrowed from the Czechs. Tilled fields encroached farther and farther out into the grasslands; but, until recent times grazing and herding remained the chief occupations of this people.[7]

The Hungarian (Magyar) peasants are serious, intelligent, and industrious. They are not as commercially inclined as are the Czechs or the Slovaks, and therefore their land holdings are operated for the welfare of the household and not for the monetary profit involved. The chief aim of the Hungarian peasant is to live a quiet life and to assure the well-being of his descendents. In their migrations, the Magyars were characterized as an obedient people and accepted the civilization, the religion, and the education of western Europe at the command of their leaders. As Doctor Leopold (*9*) says, the Hungarian peasant is no "far-western farmer" neither is he a "near-east mushik." Of Asiatic blood, this people were quick to adopt the civilization of the west and so are the meeting point of the Occident with the Orient. In recent years, they have adopted improved methods of farming, better seeds, and better breeds of livestock. The Hungarians are not so far advanced in agricultural technic as the Germans or the Czechs, but are superior to the peoples to the south and east. Much peasant grain is still harvested with a sickle, but the Hungarians have adopted the scythe and the cradle as well as the flail, whereas in Rumania, Yugoslavia, and Bulgaria these "modern" farm implements are seldom if ever seen.

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[7] The horse herder was a leading man in the village and was distinguished by a special black shirt. The cattle herder was also a personage and rode on horseback. The sheep herder went on foot or at best was seated on a donkey. (*7, p. 86.*)

The working year in Hungary is not mutilated with the untimely holidays of the nations to the south and east, and therefore farming operations are performed in a more nearly timely manner. Yields per acre obtained by the Hungarian, as well as the general quality of his farm animals, are higher than those found in the Balkans, Transylvanian Alps, the Carpathians, and the plains beyond.

As in other countries, when the nomadic clans began to settle on the land, groups of villages fell under the control of a prince or other noble. As field cultivation superseded the earlier pastoral life, these great lords retained their equity in the soil and became owners of vast estates, whereas the common people were alloted land holdings barely sufficient to maintain a family. These villagers who have dwelt in the same communties for forgotten generations are passionately attached to the soil and are strongly bound by ties of loyalty to the families of their hereditary princes or lords.

POPULATION

In 1920 the total population of residual Hungary numbered 7,980,143, of whom 7,147,053, or 89.6 per cent, claimed Hungarian as their mother tongue. There were 551,211, or 6.9 per cent, who spoke German and 141,882, or 1.8 per cent, Slovakian. Other races were represented by insignificant numbers totalling 139,997, or about 1.7 per cent.

Next after the Magyar population, the German-speaking element plays an important rôle in the economic life of the country just as it is an important factor in the economic life of Czechoslovakia. About 94,000 German-speaking Hungarian subjects lived in the large cities[8] and county seats in 1920. They are occupied chiefly with finance, commerce, and industry. There are relatively few Germans on the watershed of the Tisza River; but 330,826 are found in small hamlets, villages, and towns of lesser importance in the counties on the right and left banks of the Danube. Although it is not possible to analyze the status of this German population as to occupations it is safe to say that the great majority of them are farming colonists brought into the country by various monarchs who established small groups of these northerners among the Magyars to set an example in farm procedure. In the western counties are found 107,159 additional Germans. Those along the Austrian frontier are native to the country, whereas those more in the interior are colonists who have migrated from the north during recent centuries.

In 1910, there were 56 per cent of the population of residual Hungary dependent upon agriculture for a livelihood, as compared with

[8] Cities whose populations exceed 24,000. The only city of importance in Hungary is the capital, Budapest, whose population in 1920 was placed at 928,996, of whom 60,425 claim German as their mother tongue. This is the great commercial center in which all railway lines converge and whose position on the Danube makes it the most important river port next after Vienna. Nearly all the other large towns are "market towns" to which the surrounding farmers bring their products and whose chief activities are concentrating agricultural surpluses and supplying the simple wants of the surrounding districts. Szeged, with 119,109 inhabitants in 1920, is the commercial center of lower Hungary. It is located on the Tisza, near the Yugoslavian frontier. Debrecen (103,186 inhabitants) is the most important town in the northeast. Keeskemet (73,109) is an important grain and cattle market on the Alföld between the Danube and the Tisza. In the northwest, Györ (50,036) and in the southwest Pecs (47,556) are the most important market centers. Other large towns are Miskolc (56,982), Hodmezöyásárhely (60,922), Erzsebetfalva (40,545), Székesfehérvár (39,109), Rakospalota (36,008), Sopron (35 248), Bekes (28,161), Torokszentmilkos (26,303), Csongrad (25,888), Szarvas (25,224), and Oroshaza (24, 079). In 1920 there were 44 cities ranging from 10,069 to 19,371 inhabitants each, totaling 574,641. There were 127 large towns ranging from 5,005 to 9,985 inhabitants each, totaling 875,152. Many of these towns are largely communities of farmers and farm laborers. There were 660 towns ranging from 2,000 to 5,000 and totaling 1,696,975 inhabitants and 832 villages (1,000 to 2,000 inhabitants each), totaling 1,162,660 for the group. The remaining 1,950,254 inhabitants of Hungary lived in small hamlets and villages of less than 1,000 each.

30 per cent industrials and 4 per cent in public service. The remainder of the population formed small groups engaged in various occupations. There were 4,256,172 farming peasants and their families in 1910, as compared with 4,449,105 in 1920. During this decade, total population had increased from 7,606,971 to 7,980,143, so that the proportion of farm population remained about the same as before the World War, being 55.7 per cent of the total in 1920. As indicated in Table 3, there were increases in those engaged in commerce in transport, in public service, in the army, and in the capitalistic class, but there was a sharp decline in the number of day laborers.

TABLE 3. *Population classified according to occupation in residual Hungary, 1910 and 1920*

Occupation	1910		1920	
	Number	Per cent	Number	Per cent
Agriculture	4, 256, 172	56. 0	4, 449, 105	55. 7
Mines, industry, commerce, and transport	2, 274, 898	29. 9	2, 402, 799	30. 1
Public service	303, 445	4. 0	372, 165	4. 7
Army	63, 164	. 8	124, 600	1. 6
Day laborers	178, 015	2. 3	97, 469	1. 2
Capitalists, etc	145, 510	1. 9	196, 825	2. 5
Domestics	214, 979	2. 8	175, 461	2. 2
Other professions and unknown	170, 788	2. 3	161, 719	2. 0
Total	7, 606, 971	100. 0	7, 980, 143	100. 0

Pub. Statis. Hongroises, Recense. de la Population en 1920, 71: 1.* 1925.

THE LAND REFORM

Immediately following the World War a series of peasant disturbances developed into a Bolshevik uprising. Thousands of landless peasants, who had no means of livelihood other than the wages received for working on some large estate or for some of the more fortunate small landowners, joined forces with the idle workingmen in the large centers and temporarily gained control of the centers of government. In many cases estate owners were forced to let their modern machinery stand idle and to allow their fields to be cultivated by the primitive hand methods of the lowest class of peasants in order to give employment to larger numbers of land-hungry malcontents.

Many of these large estates had been held by individual families of the Magyar nobility for centuries; but others had been acquired by the newly rich during the World War and postwar years. It was this last class of recently acquired holdings that particularly irritated the many landless farm laborers and small farmers who did not own sufficient land for the support of an average family. These conditions led to the enactment of the Land Reform Law XXXVI of 1920; but on account of the peculiar attachment of the Hungarian peasants for the families of the Magyar nobility this land reform was not so drastic as in parts of Rumania[9] to the east, where the landed gentry was often of blood foreign to that of the common people.

At the time of the passage of the land-reform law in 1920 there were approximately 17,000,000 acres of plowland, meadows, and

[9] In Transylvania and Bessarabia.

pastures in residual Hungary. About one-third of this area, or 5,830,000 acres, was operated in holdings of more than 1,000 Jochs (1,422 acres) each. This land was owned by a very few great landlords. As indicated in Table 4, there were, in 1920, only 8,008 owners or operators of holdings of more than 100 Jochs (142.2 acres) each actively engaged in farming; whereas 548,000 heads of families owned or operated less than 100 Jochs each. In addition to the small landowners (who were aided by 574,180 members of their own families), there were 753,638 farm laborers (probably landless) and 234,019 domestics and other employees classified as gaining a livelihood by farming. Thus out of 2,118,145 active farmers and farm laborers only 8,008, or 0.38 per cent, were owners or operaters of holdings of more than 142.2 acres each.

TABLE 4.—*Active agricultural population in residual Hungary, 1910 and 1920*

Classification	1910	1920
Heads of families:	*Number*	*Number*
Proprietors of more than 142 acres	7,084	6,111
Farmers of more than 142 acres	2,124	1,897
Small owners	518,227	526,537
Planters	8,546	18,802
Herders, etc	951	500
Gardeners	2,423	2,461
Total	539,355	556,308
Other members of families helping in farm work:		
Males	266,659	303,801
Females	103,378	270,379
Total	370,037	574,180
Laborers:		
Employees	5,079	5,331
Domestic	246,286	228,688
Day laborers	516,297	753,638
Total	767,662	987,657
Grand total	1,677,054	2,118,145

Pub. Statis. Hongroises, Recense. de la Population en 1920 71:8.[4] 1925.

The land reform in Hungary was of two general types: (1) Under the first of these, known as land expropriation, certain properties of over 500 acres were subject to division among the peasants according to their local needs. The peasant had to assume responsibility for the share of the mortgage debt of the estate allotted on a pro rata basis to the land that he accepted. (2) The second type of land reform was known as wealth redemption and applied only to properties of more than 1,000 acres. It was intended to apply primarily to lands acquired since the beginning of the World War. Usually only 10 per cent of an owner's holdings have been taken, although occasionally a much larger percentage has been expropriated. Such lands were taken from the owner without compensation and had to be transferred to the State free of all encumbrances.

Most of the land that has been distributed among the peasants during the land reform has come into possession of the State under the provisions of the wealth redemption law. Only such part of any large holding acquired 50 or more years before the World War as would not jeopardize the profitable cultivation of the estate has been taken from those estates belonging to the established landed gentry.

The court in charge of readjustments of land holdings under the provisions of the land-reform law began to function on June 20, 1921, and continued until September 16, 1926. During this period 1,590,000 acres of land were assigned to new owners. Of this area, 344,000 acres were designated as sites for buildings.

The land reform has resulted in increasing the proportion of plowland held in small plots from 55.5 per cent in 1913, to 66.7 per cent in 1926.

The enactment of the land reform law in 1920 created a nervous attitude on the part of the large-estate owners toward making necessary improvements and even toward carrying out a full planting program because there was the possibility that the owners would be dispossessed of their fields. As a result of this and other deterrent factors, including the system of maximum prices fixed by the Government, about 2,548,000 acres were left unplowed in 1921.

The acreages of wheat, rye, corn, and sugar beets in 1926 had not only recovered their pre-war status, but the production of these commodities was greater than it had been before the World War, as indicated in Table 5.

TABLE 5.—*Cereals, potatoes, and sugar beets: Average production and yield per acre in present Hungary, 1909–1913 and 1926, and production and yield per acre by large and small holdings during 1926*

Crop	Total production—[1]				Production in 1926 on holdings of 100 Jochs (142.2 acres) or more[2]		Production in 1926 on holdings less than 100 Jochs (142.2 acres)[2]	
	Average 1909–1913		1926					
	Total	Yield per acre[3]	Total	Yield per acre[3]	Total	Yield per acre[3]	Total	Yield per acre[3]
	1,000 bushels	*Bushels*	*1,000 bushels*	*Bushels*	*1,000 bushels*	*Bushels*	*1,000 bushels*	*Busnels*
Wheat	71,493	19.3	74,908	20.2	23,441	20.8	45,759	18.1
Rye	31,377	19.5	31,416	18.2	10,196	19.1	19,819	16.7
Total	102,870	19.3	106,324	19.6	33,637	20.3	65,578	17.6
Barley	32,369	24.5	25,509	24.3	8,560	20.4	14,095	20.6
Oats	28,464	33.5	24,802	36.5	12,315	36.9	11,616	32.7
Corn	60,813	27.7	76,541	29.1	25,246	32.6	53,580	28.9
Total 5 cereals	224,516	23.2	233,179	23.8	79,758	25.0	144.869	21.9
Potatoes	71,118	114.9	68,880	111.3	21,944	121.2	45,386	102.9
	1,000 short tons	*Short tons*	*1,000 short tons*	*Short tons*	*1,000 short tons*	*Short tons*	*1,000 short tons*	*Short tons*
Sugar beets	1,513	11.5	1,592	10.2	1,363	9.8	144	8.5

[1] Total production average 1909–1913 and annual 1926 were taken from succeeding tables which show the latest available figures for 1926. These figures will not check with the sum of the figures for separate holdings which are preliminary and were taken from a different source.

[2] Separate holdings, 1926 (*9, p. 142*).

[3] See Table 1, for acreages.

PEASANT FARMING AND YIELDS PER ACRE

Comparing the mean yields per acre obtained in 1926 with those of 1909–1913, rye, barley, potatoes, and sugar beets averaged less than before the World War. This falling off in yield is the result of poor returns on small holdings. (See p. —.) The yields per acre for four out of the seven major crops on the large estates were greater in 1926 than the 1909–1913 average for each crop on both large estates and peasant holdings in all residual Hungary. On the other hand, the yields were less on small holdings, except in the case of corn, which was 1.2 bushels greater than the 1909–1913 average for both large and small holdings.

Among the great drawbacks to agriculture in residual Hungary are the capricious rainfall and the devastating dry winds that sweep over the great plains in early spring, at plowing time, and intermittently during the growing season. The small peasant holdings are usually located on the poorest land—stony not uniform in soil characteristics, and of such irregular shapes and small size as to preclude the use of modern machinery in the tillage of the soil.

This is in sharp contrast to the large estates, which are able to employ moisture-conservation methods—deep fall plowing, proper and timely preparation of the seed bed in the spring, and timely cultivation, especially of corn, potatoes, and sugar beets, during the growing season. The peasants not only lack a proper appreciation of the necessity for timely moisture conservation but they do not have the proper cultural implements. Consequently, when drought comes, the falling off in yield is greater on peasant holdings than is the mean falling off in the country as a whole.

On the other hand, the peasants are relatively better supplied with horse and ox power than are the estates, and if they were equipped with machinery and had sufficient technical knowledge they would be able to cultivate their larger fields, at least, more intensively than at present.

Before the World War, the peasants holding less than 284.5 acres each were in possession of 55.5 per cent of the plowlands of residual Hungary. Together with landless individuals, they owned (Table 6) 87.2 per cent of the horses, 70.3 per cent of the cattle, 84.5 per cent of the swine; but only 28.8 per cent of the sheep.

TABLE 6.—*Livestock and owners of livestock classified according to size of land holdings in Hungary, present boundaries, 1911, and total 1928*

Size of land holding	Owners of livestock	Horses	Cattle	Swine	Sheep	Goats	Mules	Donkeys
Without land	273, 880	84, 845	207, 044	896, 075	102, 206	13, 751	81	1, 979
Less than 1 arpent (1.4 acres)	34, 976	9, 089	23, 226	75, 357	7, 434	3, 420	6	271
1 to 5 arpents (1.4 to 7.1 acres)	183, 828	89, 749	25, 291	386, 095	43, 811	9, 720	50	1, 558
5 to 10 arpents (7.1 to 14.2 acres)	131, 254	137, 191	296, 602	346, 697	52, 077	3, 487	12	295
10 to 20 arpents (14.2 to 28.4 acres)	115, 195	191, 650	360, 523	438, 455	96, 641	2, 028	5	182
20 to 50 arpents (28.4 to 71.1 acres)	68, 860	178, 060	320, 312	396, 347	171, 729	1, 255	9	158
50 to 100 arpents (71.1 to 142.2 acres)	13, 901	50, 660	108, 407	117, 090	106, 225	245	1	121
100 to 200 arpents (142.2 to 284.4 acres)	4, 606	22, 944	65, 749	59, 880	98, 767	220	3	138
Total small and middle-sized land holders	552, 620	679, 343	1, 200, 110	1, 819, 921	576, 684	20, 375	86	2, 723
200 to 500 arpents (284.4 to 711 acres)	3, 121	23, 517	101, 414	71, 805	192, 040	237	34	451
500 to 1,000 arpents (711 to 1.422 acres)	1, 677	24, 672	122, 977	92, 891	278, 412	153	30	693
More than 1,000 arpents (1,422 acres)	1, 821	63, 592	369, 614	332, 726	1, 204, 296	448	182	2, 033
Total large land holders	6, 619	111, 781	594, 005	497, 422	1, 674, 748	838	246	3, 177
Total 1911	833, 119	875, 969	2, 001, 159	3, 213, 418	2, 353, 638	34, 964	413	7, 879
Total 1928	([1])	917, 974	1, 811, 647	2, 661, 539	1, 566, 451	29, 836	1, 539	4, 689

1911 calculated from Magyar Statisztikai Évkön 1912. 126–137. 1928 from Magyar Statisztikai Szemle Année 6 (7).

[1] Not available.

The advantage of numbers of animals to small holdings is not as great as at first appears because as pointed out by Kenez (*14, p. 24*): "There can be a great difference between animal, and animal and numbers alone should not form the criterion. Our large-estate owners keep heavier, better bred, and better fed animals than the small peasant farmer." The weight of livestock per 100 Jochs on small holdings is estimated at 7,500 kilograms (11,627 pounds per 100 acres), on middle-sized holdings at 5,000 kilograms (7,752 pounds per 100 acres), and on large estates at 6,200 kilograms (9,613 pounds per 100 acres).

MORE DRAFT ANIMALS REQUIRED ON SMALL HOLDINGS

Up to September 16, 1926, the administrators of the land reform had distributed 1,590,000 acres of land from the large estates among more than 390,000 petitioners. The size of the individual plots was consequently small. The practical effect of this transfer has been to remove 1,246,000 acres of land [10] from large-estate cultivation and to place these acres under the control of peasants, who were poorly equipped with implements, capital, and knowledge. In many cases the new owners also lacked proper draft animals and those that did possess horses or oxen did not own animals comparable with those on the large estates. These small parcels of newly acquired land could not be located contiguous to the fields already owned by the poor peasant. At best his new morsel of land was located at a greater or less distance from his home and usually at a distance from his former holdings. Rational cultivation of these newly acquired plots is thus out of the question.

It has been estimated that small owners of 10 to 20 hectares of plowland (24.71 to 49.42 acres) own one horse or ox for each 4 or 5 hectares (9.9 to 12.4 acres). Similarly, there is one horse or ox for each 6 or 7 hectares (14.8 to 17.3 acres) on holdings ranging from 20 to 50 hectares (49.4 to 123.6 acres). One draft animal must work 7.5 to 8 hectares (18.5 to 19.8 acres) on holdings from 50 to 200 hectares (123.6 to 494.2 acres); whereas, on large holdings between 494.2 and 2,471 acres there is only one draft animal for each 22.2 to 24.7 acres.

On the larger estates, with the supplementary use of modern machinery, more than twice as many acres can be cultivated by one animal than is the case on the smaller holdings. Following the parcellation of the land a greater number of horses or oxen have been required to till the soil than was necessary when the land was part of a large estate. In 1925 and 1926, about 680,000 acres of land were transferred to the peasants. It has been estimated that, as parts of estates, it required from 30,000 to 35,000 horses, whereas under present conditions it would need 60,000 to 70,000 horses, or the equivalent of other draft animals to maintain the soil of this acreage in a state of tillage comparable with that common to large-estate agriculture.

As in other countries, so in Hungary, the increased influence of peasant farming upon the agriculture of the country has tended to reduce field-crop production per acre below what would have been harvested had there been no change in the manner of land tenure.

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[10] A portion of expropriated land was utilized as building sites, etc.

HANDICAPS TO AGRICULTURAL DEVELOPMENT[11]

The agricultural development of the present Hungarian State is handicapped by the fact that, although the soil is in general fertile, the climate is capricious and is inclined toward extremes of heat and cold, drought, and torrential rains. Droughts are dreaded most by the small landholders whose plots of land are, as a rule, not large enough to enable them to employ machinery and are usually so situated as to render impossible the employment of proper moisture-conservation methods. During the lapse of the 27 years ended 1900, there were 63 periods of more than two weeks duration in which no precipitation occurred as follows: Three times there was a drought of 15 days duration; droughts from 16 to 20 days occurred 31 times; droughts from 21 to 25 days, 14 times; droughts from 26 to 30 days, 8 times; droughts from 31 to 35 days, 6 times; and once there was a drought continuing 55 days (*9, p. 148*).

At least twice during the year, there must be expected in Hungary periods of two weeks or more in which no moisture is added to the soil and often this period of drought occurs during the growing season. There is the further danger to production arising from dry winds, which sweep the country in March and April and dry out the newly turned furrows. Dry winds occur during the growing season and, if maximum yields are to be obtained, a constant fight for moisture conservation must be waged. For these reasons, low yields and even partial crop failures must be expected frequently. Nevertheless when climatic conditions are favorable and the soil is properly tilled, very large production is the result.

During the World War, the condition of the soil was depleted, particularly on peasant holdings, because of lack of labor and the essential implements for tillage. The numbers of livestock on feed also dropped below normal during the war period. The indirect importation of fertility through the purchase of feeding stuffs from other regions diminished and, because the customary manure was wanting, field-crop production dropped.

The Magyars settled upon the Alföld more than a thousand years ago and, for more than 10 centuries, they have tilled the soil of the plains and the hill regions of the west. There has been but little migration within the country itself. The peasants are descended through hundreds of years from ancestors, who have lived in the same village groups, who have tilled the same fields, planted the same kinds of crops, and have tended the same kinds of animals for generation after generation. Deep-seated farming traditions have been built up in almost every family concerning the manipulation of each particular field. One of the traditions most deeply seated and most universally inground into the consciousness of the Hungarian peasant is that of manuring his soil to insure to his children at least as good a chance to live as he himself possesses. To this end, he clings to his livestock.[12]

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[11] For description of physical characteristics of Hungary see (*10, p. 7*).

[12] A Hungarian peasant is very reluctant to sell his cattle in order that his year's accounting may show a profit. "Better animal husbandry at a loss, than no livestock. He will maintain the soil in as fertile a state, through use of stable manure, as he inherited it from his father." Free translation. (*9, p. 153*).

INCREASING PRODUCTION

A limited portion of the Hungarian plain could be improved by drainage, and there are other districts that would return greater yields through irrigation. It is no longer possible to graze cattle on the pastures and meadows of Hungary for the profitable production of beef, or even draft animals, without taking into consideration an appreciable return from milk and milk products. The quality of these pastures and meadows can be greatly improved and in the budgets of 1925–26 and 1926–27 the equivalent of half a million gold crowns [13] or about $101,000 were assigned for this purpose. But this amount is inadequate to cope with the problems to be solved. There are also about 500,000 Jochs (711,000 acres) of "claypan lands," of which about 200,000 Jochs (284,000 acres) can be improved.

Any improvement in agricultural production through extension and improvement of area is strictly limited. Greater progress can be made in cultural methods and improved seeds. However, as Doctor Leopold has pointed out, after all has been said, domestic animals remain the most pronounced accumulators that respond to agricultural skill. Livestock do not always bring in a cash profit, but they always represent wealth.

FERTILIZERS

The nitrogenous fertility of the soils of residual Hungary, before the World War, was maintained almost entirely by the use of stable manure and the cultivation of leguminous plants. The soil responds to the application of phosphorous of which the pre-war utilization was roughly 12,200 carloads [14] or about 134,000 short tons.

The Hungarian peasant understands the use of natural manure. Doctor Leopold, in Die Volkswirtschaft Ungarns im Jahre 1926, estimates that the cattle, horses, swine, and sheep produced enough manure, in 1926, to supply 40 quintals per Joch or 3.1 short tons per acre of plowland. It is not possible to state that stable manure is utilized with equal care in all parts of the country; but, taken as a whole, Hungary does not stand in acute need of nitrogenous manures. In 1925 the Hungarian farmers cultivated 8.45 per cent as much land to leguminous plants as to wheat, rye, barley, oats, and corn, as compared with 0.33 per cent in the old Kingdom of Rumania. In 1927 the Ministry of Agriculture distributed 2,205 short tons of superphosphates among small farmers in some 2,000 localities.

The use of phosphate fertilizers has steadily increased since the World War until 1927, when the use of superphosphates reached 177,470 short tons (Table 7); that is, it was 32 per cent greater than the estimated pre-war use.

The utilization of other fertilizers in 1927, as contrasted with their use in 1926, was as follows: Lime-nitrogen compounds, 3,869 short tons, as compared with 2,194; ammonium sulphate, 2,658 short tons, as compared with 1,720; Chili saltpeter, 1,709 short tons, as compared with 1,113; and potash fertilizers 2,976 short tons in 1927, as compared with 3,516 in 1926.

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[13] One gold crown was equivalent to 20.26 cents.
[14] One carload is 10 metric tons or 22,046 pounds.

TABLE 7.—*Superphosphates: Utilization, importation, and domestic production in Hungary, pre-war, and 1921–1927*

Year	Utilized in agriculture	Importation	Produced in residual Hungary
	Short tons	*Short tons*	*Short tons*
Pre-war years	134, 481	(1)	(1)
1921	7, 165	11	7, 154
1922	16, 534	22	16, 512
1923	47, 950	22	47, 928
1924	49, 604	2, 370	47, 234
1925	93, 695	14, 473	79, 222
1926	94, 798	22, 046	72, 752
1927	177, 470	(1)	(1)

(*9, p. 158; 15, p. 69.*) Figures converted from carloads at the rate of 10 metric tons = 1 carload.

[1] Not reported.

COMMUNICATION

There are 30.6 miles of wagon roads to each 100 square miles of territory in Hungary, as compared with 97 in Moravia and 124 in Silesia. There are 14.6 miles of railroads to each 100 square miles of territory, as compared with 14.8 miles in France. The main trade routes connecting Rumania, Bulgaria, Yugoslavia, and Turkey converge on Budapest, which is situated at the bend of the Danube as it leaves the hill country of the west and turns to flow south through the great plain (the Alföld), through Yugoslavia and thence east between Rumania and Bulgaria to the Black Sea. There are eight trunk lines radiating from Budapest, which give easy access to all surrounding States, including Poland and the Ukraine. These trunk lines are connected with a network of branch lines, which reach to all of the chief surplus-producing centers. Cheap transportation is afforded by the Danube, now an international waterway, from Budapest into Bavaria upstream and to the Black Sea downstream. There are two other navigable streams. The Tisza River affording transportation for 219 miles from the Czechoslovakian frontier south through the Alföld to Yugoslavia. The Maros River is navigable for about 16 miles from its junction with the Tisza east to the Rumanian frontier.

RELATIVE STATUS OF FIELD CROPS AND LIVESTOCK

The larger numbers of animals on small holdings presupposes a larger percentage of field products fed at home than in the case of the large estates. Before the World War it was estimated that the small peasant fed 48.86 per cent of his barley, as contrasted with 10.08 on the large estates; 70.14 per cent of oats, as compared with 40.76 per cent; and 81.57 per cent of corn, as compared with 62.08 per cent fed on large estates.

The small peasant farmer obtained 52.2 per cent of his income from the sale of animals and animal products, the middle-sized farmer 25.8 per cent, and the large-estate operator 33.9 per cent.

The relatively greater importance of domestic animals on small holdings than on those of larger size would indicate that, following the land reform, there should have been a trend toward an increase in the number of animals on Hungarian farms. However, a comparison of the numbers of livestock in 1928 with the numbers of animals in residual Hungary in 1911 (Table 6) does not reveal such an increase except in the cases of horses and mules. The number of cattle in 1928 were 90.5 per cent of the 1911 number; the number of swine, 82.8 per cent; the number of sheep, 66.6 per cent; and the number of goats, 85.3 per cent. This is in sharp contrast to the acreage of cereals, which in 1928, was 104 per cent of the 1909–1913 average, the potato acreage was 105.8 per cent and sugar beets 125.2 per cent of the pre-war averages.

The explanation of this apparent anomaly is that the numbers of animals recorded by the census of 1911 represent not only the cattle, swine, and sheep born and bred on the farms of residual Hungary but include large numbers of animals shipped in from other districts that were being fattened in the feed lots of commercial concerns engaged in the preparation of slaughter stock for the markets of Vienna, Budapest, and other large centers at the time that the census of 1911 was taken. These animals were bred for the most part in Croatia, Slovenia, and Voivodina, now parts of Yugoslavia; in Banat and Crisana, now parts of Rumania; in Slovakia and Ruthenia, now parts of Czechoslovakia; and in Galicia, now part of Poland. Not only were lean animals shipped into Hungary to be fattened for western and northwestern markets, but large quantities of feeding stuffs—hay as well as grain—were shipped to the vicinity of Budapest and the counties as far west of the Danube as the Austrian frontier from the surplus-producing districts of eastern and southeastern districts of the old Kingdom of Hungary. In all this western region the dairy industry was an important branch of farming.

PRODUCTION AND CONSUMPTION

The Hungarian villagers eat more vegetables and less cereals and meat than do the Austrians or the Czechs. The Austrians and the Czechs are strongly addicted to the use of coffee, whereas the Hungarian peasants seldom drink either coffee or tea, consequently the Hungarians use much less sugar than the peoples to the west and north. They employ honey to a large extent as a sweetener in their national cookery. Frugal and abstemious, almost every landholder has some sort of surplus to sell.

The total marketable surplus of each small holding as well as the relative quantity of products marketed is less than on middle-sized or large holdings. It has been estimated that during the course of 1902 the average small peasant farmer used at home 28.6 per cent of all the animal products and 43.4 per cent of all the field crops produced on his holdings; whereas the middle-sized farmers used at home only 3.2 per cent of his animal products and 2.7 per cent of his field crop production (*14, p. 23*). On small holdings field crops are generally fed at home to a greater extent than on large estates. The marketable surpluses as indicated above are generally in the form of some sort of animal or animal product.[15]

[15] It has been determined that the income from the sale of animals and animal products by owners of holdings of 80 Jochs (111 acres) was three and one-half times as great as the income from the sale of cereals, potatoes, hay, and straw. In similar comparison, the animal industry on holdings of 56 Jochs (80 acres) yielded five times as much as the income derived from the sale of field crops, and on holdings of 28 Jochs (40 acres) the cash income from the animal industry was twenty-two times as great as field crop returns (*1, p. 26*).

The large estates consume as food or as feed for livestock a relatively small percentage of the annual field-crop production and probably a much smaller percentage of the middle-sized holdings, almost the entire crop moving to market shortly after harvesting. The reason for this is that each large estate offers grain of a uniform quality in carload lots—usually several carloads—that can be consigned directly from the railway or river station nearest the estate to some milling center or abroad. Sometimes the middle-sized holdings are large enough to furnish a carload of uniform grain; but usually it is necessary for the buyer to assemble a carload from two or more farmers with some differences as to quality. As regards the product from the small peasant holdings, an inferior and heterogeneous quality is always to be expected.

GRAIN TRADE OF HUNGARY

In ancient times only such acreages of grain were cultivated in Hungary as were required to feed the local population of a district under the jurisdiction of an overlord and to pay the grain tax to the Austrian Empire. There were no railroads. Grain was painfully hauled up the Danube in barges or overland in rude carts to Vienna and other points west and northwest from the Magyar estates.

By the seventeenth century professional grain merchants had begun to handle this mobile surplus and, in 1635, complaints were registered from consumers in Austria (probably Lower Austria), Styria, and Moravia against the charges of these merchants. In 1751, the merchants and producers complained of the exorbitant fees collected by the customhouse agents that absorbed as much as a fourth of the worth of their grain. Some grain was sent to Italy in that century; but there was the complaint that it was not properly cleaned and that it smelled earthy.[16]

During the early part of the nineteenth century the grain trade of Hungary was concentrated in Györ and Moson northwest of Budapest and, during the period in which the United States was recuperating from the Civil War and former Russia was fighting the Crimean War, Hungary became the granary of Europe. The acreage and production of grain increased under the stimulus of high prices.

The Suez Canal, which opened in 1869, exposed Hungary to the competition of India and, beginning with 1873, the export of grain from North America cut heavily into the profits of the Hungarian farmers and the milling industry.

During this middle period of the nineteenth century the milling industry of Hungary assumed great proportions accompanied by the development of the roller-process at Budapest. Beginning with 1835 the Hungarian mills were enabled to ship grain from the Balkan States and to obtain a rebate of the tariff paid, provided that the flour equivalent of such grain was exported within a given period.[17]

Under this system the Hungarian grain dealers maintained agents or business affiliations in the chief grain-producing centers of the Balkans who bought up the better grades of wheat for shipment up the Danube to Budapest. The mill capacity of the capital and other

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[16] Formerly grain was stored in Hungary, as it is to-day in many places in the Union of Socialistic Soviet Republics, by digging a hole in the ground, pouring in the grain, and covering it again with earth. It was easy in this way to hide grain from the tax collector. In 1795 it was recommended that the Hungarians line these holes with straw in order to lessen the earthy smell.

[17] This provision continued until 1889.

centers thus developed far beyond the production capacity of the Kingdom.

With the opening of the ship canal at the Iron Gate,[18] Serbia and northeast Bosnia were enabled to ship grain cheaply down the Danube for reexport to western Europe. However, up to the outbreak of the World War, Hungary continued to purchase wheat from Rumania, Serbia, and Bosnia, for its export-flour industry.

Until 1850 the purchase of grain was not a specialized business. Traders supplied the peasantry with salt, seed, woven goods, and other simple articles, and received in barter grain, wool, hides, and other products—whatever the producer had to offer. There was no price and no grade. There were wholesale merchants in Vienna who conducted trade in export grain with central Europe. In other parts of the Austro-Hungarian Empire the grain trade was almost without exception in the hands of small traders.[19]

In the early fifties of the nineteenth century the grain-handling industry of Hungary was organized along the same general lines as in Germany with the main exchange in Budapest and minor exchanges at other important centers. From this time the export-import trade of the Kingdom was conducted more nearly independently of Vienna than had formerly been the case.

There were 51 grain warehouses in the old Kingdom of Hungary, a number of which were maintained by banks, which accepted grain as security for loans much the same as a pawnshop would accept any class of goods. But ordinarily grain is stored in all sorts of temporary warehouses.

The large mills and the warehouses at Budapest are equipped with elevators, but otherwise the grain throughout Hungary is loaded and unloaded in sacks.

There are two general classifications of grain in Hungary: (1) Large-estate grain (Herrschaftsware) and (2) peasant grain (Bauernware). Estate grain is obtainable in large lots, is uniform, clean, and of good quality; whereas peasant grain is marketed in small lots. There is great variation in the quality offered by different peasants, and the grain is indifferently cleaned.

Several varieties of each of the cereals bear trade names significant of the locality in which they are grown and the general standard of excellence for which they are known.

COMMERCIAL GRAIN

Probably more than half of the grain entering Hungarian commerce is produced on the large estates [20] and middle-sized holdings, whereas nearly half (43.4 per cent in 1902) of the field crops of the small holdings does not leave the producers.

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[18] The point at which the Danube River breaks through the Transylvanian Alps, on its passage to the Black Sea, is called the Iron Gate (fig. 1) on account of the narrow gatelike defile through which the river flows in a succession of unnavigable rapids. In 1898, a canal accommodating small ships was constructed about these rapids.

[19] A list of the names of these traders shows not only that the products of Hungary were handled by Armenians, Greeks, Jews, and Serbs but that also Magyars engaged in trading "mit Eifer und Verstandnis [with eagerness and understanding]" (4).

[20] If it is assumed that the small peasants (holdings less than 100 jochs, 142.2 acres each) and estates (holdings more than 100 Jochs each) consumed relatively as much of their products on the farm as they did before the World War the marketable surpluses, in 1926 would have been barley, 7,208,000 bushels produced by the peasants as compared with 7,697,000 bushels produced by the estates; oats, 4,630,000 bushels of peasant grain as compared with 7,295,000 produced by the estates; and corn, 9,875,000 bushels of peasant grain as compared with 9,573,000 bushels produced by the estates. The estates consumed relatively a small quantity of the 33,637,000 bushels of wheat and rye produced in 1926, whereas a very large proportion of the 65,578,000 bushels produced by the small peasants did not leave the farm.

Taking Hungary as an illustration of an exporting country, the ultimate disposition of the Hungarian grain crop during the course of any one crop year (August 1 to July 31) is the result of a long and complicated series of reactions between several groups of factors that may be considered as having operated to produce one of two possible results: (1) To cause the wheat to be exported; or (2) to cause the wheat to disappear in some other manner.

The second group of factors includes all those factors that tend to keep wheat off the market; that is, to reduce the quantity of commercial wheat. In this group of factors is the use of wheat as seed. The quantity of seed used from the crop harvested in the summer of any one year for the crop of the next year fluctuates directly with the acreage of the crop of the succeeding year. The seed requirement has always to be met and, under Hungarian conditions, is almost universally, supplied from grain produced on the farm itself although, exceptionally, it is purchased from domestic or imported wheat. There is always a greater or less quantity of unmarketable grain—if not on every farm at least within the country as a whole. The quantity of such grain that is not used for human food and that is customarily fed to livestock fluctuates from season to season and is generally affected by the price receivable by the farmer. When grain is scarce and prices high, there is a tendency on the part of the seller to crowd as much low-grade grain as possible into the marketable grades. The price of grain, on the other hand, might be so low that the farmer would feed all but the choicest portion of his crop. There are also losses at the farm on account of pests, spoiling, and accidental destruction.

Then there is the food requirement of the farmer's family, the feed for his livestock, and the reserve supply to be held at the farm for use in an emergency. Both the food and feeding stuff requirement, as well as the reserve supply, fluctuate from season to season, depending upon the manner in which the farm population of Hungary reacts to the economic and other conditions determining the prices that affect their daily life. This involves the question as to whether it is more to the farmer's advantage to eat or feed a larger part of his grain than had previously been the general practice of his household, or to sell a greater than normal portion.

The manner in which the Hungarian farmer reacts to changes affecting his daily life is governed largely by his racial characteristics; that is, by the customs and habits of the Hungarian nation, which differ materially, for example, from those of the German farmers on the one hand, and from those of the Rumanian peasants on the other. That is to say, a series of reactions tending to keep wheat off the market will be attended by an end result in Hungary characteristic of the Hungarians, whereas a similar series of reactions would not necessarily produce a similar effect in Rumania, where the end result would be typical of the very different racial characteristics of the Rumanian farmers. As a result of all this class of reactions, a certain portion of the wheat crop of every country, whether an exporting or an importing nation, remains immobile each year in contradistinction to the commercial portion of the crop which moves to market.

The acreage devoted to cereal-crop production in Hungary fluctuates relatively little from year to year, and the seed requirement deviates over a more restricted range than does the food and feed requirement. The relations between crop production and export are considered to be the relation of net production (gross production of a given year less the seed requirement for the crop of the succeeding year) to the net export (gross exports less imports).

When the commercial portion of the crop begins to move from the farms of Hungary, an army of intermediaries appears to speed the grain along only as rapidly and only as far as it is profitable for them to handle it. Village gristmills and customs mills of county seats offer a strong barrier against the movement of wheat beyond local boundaries. Village and provincial bread requirements in Hungary are governed by food habits that are typical of Hungarian racial characteristics, which are distinctly different from the food habits of the Germans or the Rumanians. To supply the local bread and feed requirements, a large part of the local production is withheld from the large market centers where grain is concentrated in large or wholesale quantities. This grain is for the most part consumed as bread for humans and feeding stuffs for livestock, although there are losses all along the line, and always stocks of grain, meal, and flour of varying magnitude are carried over at the end of each season by local merchants and small customs mills.

In Hungary and in other countries in which large estates still operate, there is a marked difference in the quality of peasant and estate grain. Relatively little grain produced on small holdings, which is of low grade and lacks uniformity,[21] flows beyond the local grist and customs mills. Only the best grade finds its way to the large market centers because the large buyers can make a profit only by handling the best. On the other hand, very little estate grain is ground locally, because it is of uniform grade and can be purchased in large quantities. The general quality of the grain produced on each estate in Hungary is known to the buyers, who usually contract for the entire crop in advance so that, as soon as threshed, estate grain begins to move to Budapest or some other large concentration center conveniently situated on the Danube or on some trunk line of commerce, for utilization by the large commercial mills or for export.

Before the World War, many of the large grain-handling firms and mills in the western and northwestern districts of the Austrian Empire maintained agents in the various production centers of the old Kingdom of Hungary to buy up the quantities and particular grades of hard wheat (steel wheat) that they required for blending with their softer local varieties. On the average, before the World War, about one-third of Hungary's wheat export was shipped abroad in the form of grain. About two-thirds of the export wheat was shipped abroad as flour by the great exporting mill combines of Budapest and from certain provincial milling centers, which maintained contacts with selling organizations in Vienna and in other cities of the Austrian Empire as well as in central Europe.

Under conditions of unrestricted commerce, the quantity of grain that the merchants and mills of a surplus country attempt to export

[21] In Hungary, as in most parts of central and southeastern Europe, peasant holdings consist of long narrow strips of land. These strips of land are seeded (broadcasted) by hand. If a peasant plants carefully selected seed it is improbable that his neighbors on the right and left will plant seed of equal quality. It is possible that the neighbor on the right will sow an entirely different kind of crop and the one on the left still another kind. The seed sown by each neighbor scatters over onto the field of the peasant lying between so that when this peasant harvests his grain it is usually of three qualities and may be an admixture of three different cereals. Attempts have been made to correct this evil; but to date these attempts have not been followed by a general reform

does not take into conscious consideration any particular quantity of grain required for domestic utilization. The exporters attempt to buy up and ship from the country the maximum quantity of wheat that, in their opinion, will give them a profit. These operations are conducted in competition with local mills, which buy and grind for local and general domestic consumption the maximum quantity of wheat that, in their opinion, can be sold at a profit to the native population.

The reactions between cost at shipping point, freights, mill expenses, and the multitude of factors involved in transportation, processing, and merchandising interposed between the date of purchase and the date of final sale determine the accuracy of their guess and eventually fix the quantity handled.

There are two groups of agencies in competition in any surplus-producing country:

(1) The exporting organizations with foreign contacts strive to make the greatest possible profit by shipping abroad a maximum quantity of grain from any possible source. This quantity is modified by certain price considerations.

(2) The local organizations with domestic contacts strive to make as great a profit as possible out of the maximum quantity of grain that the domestic population, also governed by price considerations, will utilize.

Both groups, at the end of any one season, carry over within the country itself stocks of grain, meal, and flour, that fluctuate in magnitude from season to season. The quantity of grain that eventually finds its way abroad, as well as the quantity that disappears each year within the country itself, is the end result of several complex reaction series involving a vast number of fluctuating factors.

Before the World War the flow of grain and flour out of the old Kingdom of Hungary was almost exclusively in the direction of some center of demand in the former Austrian Empire. This flow was facilitated by lack of customs restrictions between the two countries, and the tariff regulations of the Dual Monarchy protected both Austrian and Hungarian grain from the sharpness of world competition. For this reason the annual amount of the grain flow depended upon the pressure of the accumulated supply in Hungary against the restraining barriers of the Hungarian domestic demand, as well as upon the pull or suction of the centers of demand in Austria, tending to break down restraining barriers, not only in Hungary, but in the other sources of supply, from which the deficit districts of the old Austrian Empire drew grain to satisfy their food and feed requirements.

CEREALS

In recent years the cash income of the peasant farmers and estate owners of Hungary has been derived more and more from the sale of animals and animal products. As a source of natural manure, the animal industry has been indispensable to the maintenance of soil fertility; nevertheless cereal production is still the chief occupation of the Hungarian farmer. Among cereals, wheat is outstandingly the most important crop produced.

WHEAT

Before the World War (1909–1913) the acreage seeded to wheat in the territory comprised within the present boundary of Hungary averaged 3,712,000 acres. In 1921–22 this acreage had decreased to 2,888,000 acres. The decrease in the wheat acreage, accompanied by drought, lack of fertilizers, lack of labor and farm power, lack of training on the part of the peasants, and lack of capital, all combined to reduce the net production of wheat during 1921–22 at least 18,000,000 bushels below the pre-war normal, and Hungary exported only 9,091,000 bushels of wheat in the form of grain and flour during the crop year. The following year, although net production increased 2,664,000 bushels, exports fell to about 5,000,000 bushels. (Table 8.) From then on exports more nearly assumed their pre-war importance.

TABLE 8.—*Wheat: Statistical balances of Hungary, old boundary, 1904–5 to 1913–14; new boundary, average 1909–1913, and annual, 1920–21 to 1928–29*

Crop year	Population [1]	Acreage [2]	Seed [3]	Production		Disappearance		Net exports [5]
				Gross [2]	Net [4]	Statistical	Per capita	
Former boundary:	*Number*	*1,000 acres*	*1,000 bushels*	*1,000 bushels*	*1,000 bushels*	*1,000 bushels*	*Bushels*	*1,000 bushels*
1904–5	19, 907, 331	9, 130	26, 349	146, 918	120, 375			[6] 8, 076
1905–6	20, 070, 524	9, 197	26, 543	170, 588	143, 113			[6] 17, 805
1906–7	20, 233, 717	9, 520	27, 475	207, 758	182, 428	117, 205	5. 79	65, 223
1907–8	20, 396, 910	8, 777	25, 330	130, 677	103, 335	59, 533	2. 92	43, 802
1908–9	20, 560, 103	9, 474	27, 342	165, 424	140, 030	97, 489	4. 74	42, 541
Average 1906–7 to 1908–9	20, 396, 910	9, 257		167, 953	141, 931	91, 409	4. 48	50, 522
1909–10	20, 723, 296	8, 799	25, 394	125, 015	97, 959	85, 579	4. 13	12, 380
1910–11	20, 886, 487	9, 375	27, 056	181, 138	154, 696	106, 650	5. 11	48, 046
1911–12	21, 049, 680	9, 162	26, 442	190, 081	162, 448	107, 524	5. 11	54, 924
1912–13	21, 212, 873	9, 575	27, 633	184, 639	160, 013	107, 496	5. 07	52, 517
1913–14	21, 376, 066	8, 533	24, 626	167, 347	141, 771	100, 131	4. 68	41, 640
Average 1909–10 to 1913–14	21, 049, 680	9, 089		169, 644	143, 377	101, 476	4. 82	41, 901
New boundary:								
Estimated average 1909–1913	7, 606, 971	3, 712	10, 542	71, 493	60, 951	40, 462	5. 32	[7] 20, 489
1920–21	7, 980, 143	2, 662	7, 560	37, 927	29, 725	29, 731	3. 73	[8] −6
1921–22	8, 065, 537	2, 888	8, 202	52, 715	42, 713	33, 622	4. 17	9, 091
1922–23	8, 111, 465	3, 522	10, 002	54, 729	45, 377	40, 412	4. 96	4, 965
1923–24	8, 221, 149	3, 293	9, 352	67, 705	57, 768	41, 370	5. 03	16, 398
1924–25	8, 274, 940	3, 499	9, 937	51, 568	41, 560	28, 357	3. 43	13, 203
1925–26	8, 368, 273	3, 524	10, 008	71, 675	61, 150	41, 667	4. 98	19, 483
1926–27	8, 413, 957	3, 706	10, 525	74, 908	63, 488	41, 873	4. 96	21, 615
1927–28	8, 519, 641	4, 021	11, 420	76, 933	65, 195	43, 704	5. 13	21, 491
1928–29	8, 595, 325	4, 133	11, 738	92, 037	80, 299			

[1] Population 1904–1909 estimated by interpolating the increase between 1900 (19,254,559) and 1910 as given in Magyar Statisztikai Évkön. 1915: 7. In 1900 there were 1,981,395 inhabitants in municipalities and 2,338,262 in 1910. 1911–1913 estimated by assuming the increase to be at the same rate as previous years. 1910 population for new boundaries used for 1909–1913 average, and 1920 from Recensement General de la Population de 1920: 28. 1921–1924 estimated by adding births and subtracting deaths as given in Statesman's Year-Book 1926 (*8, p. 986*)–to 1920 population. 1925 from Internatl. Yearbook Agr. Statis. 1926–27: 2 1926, 1927, and 1928 estimated by assuming that the same average yearly increase had occurred as between 1920 and 1925.

[2] Acreage and production from official records of U. S. Department of Agriculture, Bureau of Agricultural Economics.

[3] Old boundary, 2.886 bushels per acre and new boundary 2.84 bushels per acre (*10, p. 13*).

[4] Seed for acreages the following year subtracted from production for stated year, except average 1909–1913 and annual 1928–29.

[5] Years beginning Aug. 1, 1904–5 to 1913–14, old boundary, from Ann. Internatl. Statis. Agr. 1913–14: 120–127; 1920–21 from Ann. Internatl. Statis. Agr. 1923. 1921–22 to 1927–28 from Internatl. Yearbooks Agr. Statis. 1924–25 and 1927–28. Exports include wheat and wheat flour in terms of grain except as noted.

[6] Does not include wheat flour.

[7] Surplus.

[8] Net imports.

INTERNATIONAL TRADE IN WHEAT

The old Kingdom of Hungary exported (net) on the average 41,901,000 bushels of wheat as grain and flour during the 5-year period ended July 31, 1914. During this period, the wheat and flour exports from the territory now constituting Hungary are estimated to have been equivalent to 20,489,000 bushels of wheat. A large portion of the wheat shipped from the outlying territories of the former Kingdom, which, since the World War, have become parts of Rumania and Yugoslavia, was exported up the Danube as grain to present Czechoslovakia and Austria, whereas most of the wheat shipped from the territories now comprising Hungary was exported as flour.

The drought of 1922 discouraged and even prevented the seeding of winter wheat for the crop of the succeeding season so that the total area of wheat in 1923 fell 229,000 acres below that of the previous year. The harvest of 1923 was comparatively favorable, and the net production of wheat nearly reached the pre-war average. In this year, the Government took direct charge of exports and, although a total of 16,398,000 bushels in the form of wheat and wheat flour was shipped abroad, domestic disappearance of wheat exceeded the pre-war normal. Then came the short crop of 1924. Net production was hardly sufficient to meet the food requirements of the nation. Nevertheless, 13,203,000 bushels of wheat were exported, forcing the city populations to go on very short supplies and the entire nation to resort to substitutes. Per capita disappearance dropped to 3.43 bushels. The harvest of 1925 was exceptionally good; but the agricultural industry and the country as a whole was engulfed in a crisis caused by a sharp decline in prices, illustrated by the rapid fall in the price of wheat during the 12 months ended December 31, 1925, according to the monthly quotations on the Budapest market as indicated in Table 9.

TABLE 9.—*Wheat: Average price in Budapest, by months, January, 1922–December, 1925, and January, 1927–July, 1928*

[See Table 54 for average values of the crown and pengö]

Month	1922		1922–23		1923–24		1924–25		1925–26		1926–27		1927–28	
	Crowns per quintal	Cents per bushel	Crowns per quintal	Cents per bushel	Crowns per quintal	Cents per bushel	Crowns per quintal	Cents per bushel	Crowns per quintal	Cents per bushel	Pengös per quintal	Cents per bushel	Pengös per quintal	Cents per bushel
August			6,853	112	78,020	212	106,406	114	381,677	145	(1)		30.58	145
September			8,982	98	91,216	218	114,150	147	373,177	142	(1)		30.92	147
October			11,252	122	94,776	258	149,263	159	366,227	140	(1)		30.52	145
November			10,398	113	101,263	276	460,677	163	359,200	137	(1)		30.33	144
December			10,360	113	108,198	294	196,823	176	400,833	153	(1)		30.71	146
January	2,312	94	12,454	136	133,568	142	585,917	215	(1)		[2] 33.00	157	31.20	148
February	2,460	100	12,880	140	227,877	205	587,967	224	(1)		[2] 34.00	162	31.72	151
March	2,781	98	16,103	131	310,808	127	522,952	199	(1)		[2] 34.51	164	33.35	159
April	3,140	111	23,587	128	315,469	120	513,787	196	(1)		(1)		33.94	161
May	3,414	122	25,955	141	339,880	120	504,734	192	(1)		[2] 35.00	166	34.15	162
June	3,933	118	33,288	91	312,051	102	519,593	198	(1)		32.04	152	34.20	162
July	5,946	129	51,275	140	358,187	117	419,011	160	(1)		30.13	143	29.41	140

January, 1922, to July, 1928, from Inst. Internatl. de Statis.-Bul. mensuel de l'Office Permanent.

[1] Not available.

[2] End of month. From *3, p. 71*.

In spite of this decline in wheat prices, the 1926 planting showed an increase over the preceding year and was only 6,000 acres below the 1909–1913 average. Production was higher than before the World War, being 74,908,000 bushels as compared with 71,675,000 in 1925 and an average of 71,493,000 during the 5-year period ended 1913. In 1927 there was a further increase in acreage and production, the former was 309,000 acres above the pre-war average, and the latter was 5,440,000 bushels above it.

Yields per acre were below those obtained before the World War, until the year 1925, when 20.3 bushels of wheat per acre were obtained, as compared with the pre-war average of 19.3 bushels. In 1926, the yield was 20.2 bushels per acre and in 1927, 19.1 bushels.

A comparison of the trade for the calendar year 1925 with that of the preceding year shows a marked increase in the export of wheat followed by a still greater increase during 1926. During 1926 Hungary exported 6,719,937 bushels of wheat to Austria, 4,180,726 bushels to Czechoslovakia, 2,915,264 bushels to Italy, 584,083 bushels to Germany, 292,940 bushels to Poland, and 83,823 bushels to Switzerland. The total export for the calendar year was 14,831,013 bushels, as compared with 8,007,875 bushels in 1925. Thus the rise amounted to about 85 per cent, but against this increased export of wheat stands a sharp decrease in wheat flour exports from 2,153,811 barrels in 1925 to 1,654,862 barrels during 1926. The total export figures for 1925 are from Annual International Statistics of Agriculture, 1925–26; the total export figures for 1926 are from Statisztikai Havi Közlemények, October, December, 1926.

TABLE 10.—*Wheat and wheat flour:*[1] *Imports and exports of Hungary, 1904–5 to 1913–14 and 1919–20 to 1927–28*

Year	Wheat		Wheat flour	
	Imports	Exports	Imports	Exports
Pre-war years:	*Bushels*	*Bushels*	*Barrels*	*Barrels*
1904–5	5, 404, 867	13, 481, 276	----------	----------
1905–6	2, 589, 755	20, 394, 898	----------	----------
1906–7	122, 936	24, 919, 611	72, 162	9, 055, 819
1907–8	449, 533	16, 221, 568	92, 762	6, 321, 496
1908–9	1, 903, 874	13, 572, 212	63, 371	6, 923, 951
1909–10	22, 405, 111	7, 525, 564	139, 732	6, 197, 252
1910–11	1, 277, 092	16, 531, 244	99, 840	7, 386, 934
1911–12	1, 331, 288	18, 609, 223	69, 938	8, 435, 781
1912–13	703, 767	16, 685, 768	73, 824	8, 192, 771
1913–14	7, 911, 773	16, 313, 996	159, 642	7, 545, 699
Post-war years:				
1919–20	64, 966	9, 190	105, 347	742
1920–21	----------	1, 775	53, 525	51, 823
1921–22	4, 380	710, 249	242	1, 863, 620
1922–23	223, 455	70, 301	141	1, 137, 580
1923–24	3, 715	5, 904, 169	9	2, 332, 827
1924–25	649, 787	4, 739, 111	1, 998	2, 027, 243
1925–26	31, 467	11, 335, 947	17	1, 817, 434
1926–27	592	14, 471, 604	17	1, 587, 492
1927–28	1, 487	12, 005, 733	22	2, 108, 194

1904–5 to 1913–14 from Ann. Internatl. Statis. Agr. 1913–14.
1919–20 and 1920–21 from Ann. Internatl. Statis. Agr. 1922–23.
1921–22 from Ann. Internatl. Statis. Agr. 1924–25.
1922–23 and 1923–24 from Ann. Internatl. Statis. Agr. 1925–26.
1924–25 to 1927–28 from Ann. Internatl. Statis. Agr. 1927–28.
These data can not be considered comparable owing to frontier alterations during the period under review.

[1] Fiscal year Aug. 1 to July 31.

Trade in wheat was fairly brisk during the first half of 1927. The stagnation which had prevailed toward the end of the previous year, gave place to an animated inquiry toward the end of January. This is explained by the fact that wheat in storage had been exhausted, and both Austria and Czechoslovakia, as well as the Hungarian mills, found it necessary to replenish their wheat supplies. Wheat was quoted at 33 pengös per quintal (157 cents per bushel) at the end of January; at the end of February, at 34 pengös; at the end of March at 34.50 pengös; and at the end of May, at 35 pengös per quintal, on an average of 164 cents per bushel. The world market however did not keep pace with these advances; the Chicago quotation for wheat, in the middle of January, was 143 cents and fell to 137 cents by the middle of February. For this reason Italy canceled a number of her earlier orders in Hungary. In June, the demand for wheat greatly subsided and, under the effect of favorable harvest prospects, prices fell to an average of 32.04 pengös during the month. (Table 9.)

Trade in wheat began at a slow rate immediately after the harvest of 1927. The farmers considered the market prices too low and were in no hurry to market their wheat; but as they needed money the storage of wheat against advances in cash underwent an unusual development.

Throughout the campaign, western markets evinced only a slight interest in Hungarian wheat, and prices remained low throughout the last six months of the year, fluctuating around 145 cents per bushel. On the other hand, the quotation in Chicago fell from 143 cents, on July 15, to 128¾ cents at the end of December; that is, more than 10 per cent. For this reason Hungary was practically excluded from the export trade in wheat, greatly reducing the year's total, which was 23 per cent less than that of 1926, although it exceeded that of 1925. The detailed export data for the year 1927 were as follows: Czechoslovakia, 5,435,805 bushels; Austria, 4,378,361 bushels; Poland, 1,058,902 bushels; Italy, 431,470 bushels; Germany, 107,548 bushels; Switzerland, 12,860 bushels; Yugoslavia, 10,788 bushels; and Rumania, 658 bushels. (*3, p. 71–72.*)

MILLING

Next after Minneapolis, Budapest is said to be the largest milling center in the world. From the standpoint of capital invested, number of persons employed, ready accessibility of raw material needed, value of products, and general importance to the national economic structure of the State, flour milling easily takes first rank over all other industries in residual Hungary, representing fully 50 per cent of the total industrial activity of the country.

The commercial and export industry is centered at Budapest, where the first roller mill in the world is said to have been put into operation. There were 4 great mill combines at the capital, with a total capacity of 937,000 short tons annually. There were some 300 commercial mills scattered throughout the country districts in 1923. Grist and meal were ground for local consumption at several hundred small village mills driven by power from diverse sources.[22]

[22] There were 20,726 mills in the old Kingdom of Hungary in 1906. Of this number 2,040 were modern steam mills and 183 combined steam and water mills. There were 562 motor driven (oil and gas) mills. Windmills had decreased to about 700, and primitive animal-driven mills (trocken muhlen) to 651. Most of the mills were driven by water. Of a total of 16,590 such mills, 7,895 were fitted to grind only corn. These mills were found in the mountainous districts of Slovakia, Seven Mountains, Caras Severin, and Croatia. There were 3,717 water mills fitted to grind wheat and 2,278 specialized in rye. (Die ungarische Mühlen industrie. An article in Magyar Közgazdaság és Kultura, 1913, p. 12.)

The total capacity of all flour mills in Hungary has been placed at 4,400,000 short tons, whereas the pre-war estimated production of bread grains within the present boundaries of the country was approximately 1,828,530 short tons of wheat and 741,692 short tons of rye. That is, before the World War, all of the locally produced wheat and rye in Hungary would, on the average, have supplied grist to keep the mills of the country running at 58.4 per cent of their registered capacity. It would have been necessary to have imported 1,830,000 short tons of grain, equivalent to about 61,000,000 bushels of wheat, to have kept these mills running at full capacity.

The great commercial flour industry of Hungary was the outgrowth of a demand in central Europe for a flour made from the hard wheat developed under the conditions of climate and soil found on the plains of Hungary called Stahlweizen or steel wheat, which possesses superior milling and baking qualities. The Austro-Hungarian Monarchial Government fostered the industry by perfecting the access of the Budapest mills to the great grain-surplus regions of Crisana and eastern Banat, now parts of Rumania, and of Voivodina, now part of Yugoslavia. On the other hand, this great milling center was favored by special privileges in the protected markets of Galicia, now part of Poland; in Bukovina, now part of Rumania; in Croatia, Slavonia, Slovenia, Bosina, and Dalmatia now parts of Yugoslavia; and in the territories now comprising Czechoslovakia and in those constituting the Republic of Austria including the city of Vienna with a population of nearly 2,000,000.

The boundary lines established by the treaty of Trianon set up customs barriers that have cut off a large percentage of the pre-war supply of raw materials that had formerly been shipped from outlying districts to the mills now located in Hungary. In like manner, these mills have been cut off from fully 42,000,000 consuming population who had formerly looked to Hungary to supply flour to supplement their insufficient local production.

Before the World War, the population of Hungary consumed about 1.4 bushels of rye per capita each year. This is equivalent to 45.7 pounds of rye flour. They also consumed 5.32 bushels of wheat, which is equivalent to 231.7 pounds of wheat flour per capita per annum. The application of these norms to the 1926 population of Hungary indicates that had the pre-war normal bread requirement been consumed the national demand would have been for 978,232 short tons of wheat flour and 192,944 short tons of rye flour, representing about 26.6 per cent of the registered grinding capacity of all Hungarian mills.

The 1926 net production of wheat was equivalent to 1,390,000 short tons of flour [23] and that of rye to 431,000 short tons,[23] or 650,000 short tons more than would have been required to supply the Hungarian population with their pre-war per capita rate of consumption. The capacity of the Hungarian flour mills was thus sufficient not only to grind all of the domestic production of wheat and rye but an additional quantity of grain equivalent to 2,579,000 short tons of flour.

On the basis of the pre-war demand for flour in Hungary, the 1926 requirement would be about 26.6 per cent, whereas local production

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[23] It is estimated that 4½ bushels of wheat will mill 1 barrel of wheat flour (196 pounds), and that 6 bushels of rye = 1 barrel of rye flour (196 pounds).

in the same year was equivalent to 41.4 per cent of the grinding capacity of the mills located in this territory.

Had Hungarian mills run at full capacity in 1926, they would have been required to import 58.6 per cent of the grain ground and to export at least 73.4 per cent of the flour produced. This is the crux of the present situation.

It is obvious that the economic development of Hungary is closely bound up with the milling industry. The great need of the animal industry of the country is concentrated feeding stuffs, and for this reason alone every pound of grain that can be obtained by the mills should be ground within the country itself, and the resulting bran and other by-products should be fed domestically to increase exportable surpluses of dairy and other animal products and to build up the fertility of the soil. The pursuit of any other policy is practically equivalent to diminishing a chance of future generations having a fair opportunity to earn a livelihood from that soil unless fertility is restored by use of commercial fertilizers.

Instead of pursuing a policy of developing the milling industry and facilitating the exportation of flour, the action taken by the Hungarian Government resulted in forcing the exportation of native wheat and placing the mills in the position where they either had to lie idle or import foreign wheat. Thus, in 1922, the milling industry was stagnated by the imposition of an export tax of 65 quintals of wheat on each 10 metric tons of flour, or 212 bushels for every 100 barrels of flour made from native wheat. Since there was a tax of only 8 quintals (29 bushels) of wheat per 10 metric tons of exported flour made from foreign wheat, the Budapest mills shipped in grain from Manitoba for milling and reexport, leaving domestically produced wheat to be consumed within the country itself or to be exported as grain.

The milling industry had barely adjusted its operation to this tax system when the Government abandoned this plan and levied a tax of 5 per cent on wheat purchased by mills, and an additional tax of 10 per cent was placed on all wheat milled. The foreign exchange obtained from the sale of flour abroad had to be turned over to the central foreign exchange committee at rates less than the regular market quotations. This so discouraged milling that the industry operated at only about one-fourth capacity. Under such conditions the Hungarian mills were unable to hold the markets in central Europe that had formerly been supplied almost exclusively with Hungarian flour, and this product was replaced to a large extent by flour from the United States and other countries. Flour from the United States was sold extensively in Czechoslovakia, Austria, and Dalmatia, where formerly the popular belief had been that no flour was equal to Hungarian for pastry purposes. This belief has been dispelled.

The following year, 1923, the milling industry received a further setback, for, under pressure for funds, the Hungarian Government was forced to take over the export of grain for its own account, greatly to the injury of both the millers and grain merchants of the country.

The Royal Hungarian Ministry for Public Provisioning passed a regulation standardizing flour at a lower grade than formerly was maintained at Budapest, and, thus, practically placed the quality of the flour produced by the Budapest mills on a parity with that produced in the Comitats, to the advantage of the latter. The small mills operate with smaller costs and also buy their grain, for the most part, in the immediate neighborhood, and therefore at lower prices, and are indeed, in their own districts, the strongest competitors of the great mills. These great mills, at the capital, unable to meet competition in foreign markets on account of being hampered by export taxes in addition to milling taxes, thus found themselves unable to meet home competition on account of freight rates. Severe losses were suffered, both at home and abroad, and the mills became so involved in debts that, in 1925, two great combines went into bankruptcy.

In 1926, the competition of the small mills was carried into Budapest itself. The metropolitan mills worked up 213,053 short tons of wheat and rye, which, including fodder meal, corresponds to about 172,510 short tons of flour. During 1926, a total of 143,078 short tons of wheat flour and rye flour were shipped into Budapest, giving the city a gross supply of 315,588 short tons. Of this amount, 104,215 short tons of flour were exported, of which the Budapest mills supplied 96,215 short tons. This left 211,373 short tons as the net supply of the metropolis, of which only 76,295 short tons were ground by the great mills and 135,078 short tons were shipped in by the smaller, country mills.

The increased difficulty of marketing their products in 1926 reduced the quantity of grain ground by the Budapest mills and more important country mills (that rendered reports) to about 24.3 per cent of their annual grinding capacity.

The following year, two large mills were made over into woodworking plants for house-construction material; two others were transformed into warehouses; and one mill remodeled its machinery to polish rice. Many other mills stood idle during the whole or part of 1927.

The introduction of the 1-phase system of turnover tax—that is, the release of mill products, in traffic outside the mills, from the turnover tax—had also the result that the wholesale trade in flour and mill products, which for the first half of 1927 was almost condemned to inactivity through the still existing 2 per cent turnover tax, began slowly to recover and to share with the mills in the business of trading.

The natural markets for Hungarian flour are those of the two near-by States of Austria and Czechoslovakia, whose production of wheat and rye is insufficient to cover the food requirements of their own populations. Three conflicting sets of interests have developed in each of these countries. The city populations demand cheap bread, the farmers contend for a just compensation for their wheat, and the millers require a margin of profit on their locally produced flour. The sale of flour from the United States and Canada in each of these countries is also firmly established. Thus, in the face of tariffs to protect the farmer and the local miller, as well as the offerings of cheap overseas flour, the Hungarian mills will find it extremely difficult to reestablish themselves in the Alpine Provinces of Austria to the west or in Bohemia, Moravia, and Silesia, where the bulk of the output of the Budapest mills was sold before the World War. It is to the advantage of both Austria and Czechoslovakia, on the west and north, to grind as much wheat as possible within their own frontiers and to import as little flour as possible.

It is to the interest of Yugoslavia, on the south, to export less wheat and to develop its own milling industry sufficiently to supply the needs of Dalmatia, Bosnia, Herzegovina, Montenegro, Slovenia, and western Croatia. Each of these territories was accustomed, before the World War, to look to Budapest for part of its flour requirement.

The needs of Bukovina, on the east, are now being met by the mills of Rumania, whereas Galicia, to the north, which formerly looked to central Hungary for a portion of its flour requirement, has covered its deficit by purchases at more readily accessible sources of supply, its customs tariffs being prohibitively high for Hungarian products.

The former Hungarian territories of Banat and Crisana, that are now parts of Rumania, possess great mills of their own and under favorable conditions are able to compete with Budapest for western and northern markets.

Hungarian flour has to struggle against high customs protection in nearly every customer country and to meet the competition of flour from 13 or 14 other countries, all of which have to face the fierce competition of the milling industry of the customer country itself.

The Hungarian milling industry will have to find new markets, but whether in Switzerland, Greece, France, or Brazil they will have to meet the competition of the world market. It is improbable that the milling industry of Hungary can recover its former position of importance among the industries of the country. Just as had occurred in Czechoslovakia, it is probable that many mills in Hungary will be abandoned and dismantled. Those mills that survive this crisis will be forced to reorganize their business in the face of strong competition from American flour, which has established a reputation for quality among the bakers and housewives of Europe who formerly held Hungarian flour indispensable to their needs. This reorganization will probably be in the direction of combining the milling interests under fewer administrative units to cut down the costly overhead.

THE RELATION OF PRODUCTION AND DISAPPEARANCE TO THE EXPORT OF WHEAT

In countries of surplus production in southeastern Europe, where the export of cereals is a factor of first importance to the balance sheet of international trade, it is customary for governments to issue, during the summer, statements regarding the probable exportable surplus of wheat, rye, etc., from the crop about to be harvested. These statements are, customarily, calculated from a hypothetical consumption norm based upon averages of past years. Such forecasts may or may not approximate the export that follows the marketing of the crop. Many modifying factors may inject themselves into the situation during the 12 months following the harvest. Among these factors are the price situation as regards wheat and rye in an exporting country in relation to prices in customer and competing countries; fluctuations in exchange rates, shifts in tariffs and trade regulations both at home and abroad; the geographic relation of surplus areas to deficit areas within the country itself and to the consuming centers of customer countries; the relative size of the wheat surplus to the size and price of substitute products such as rye or potatoes. The continual play of changes in these and other factors tends to modify any estimate that may be made regarding the probable domestic requirement and the probable exportable surplus in their relation to the production in any given crop year. Nevertheless, there are certain basic principles of relationship existing among production, disappearance, and export that can be expressed mathematically in such a way as to aid in analyzing or at least in visualizing the interplay of factors that affect the movement of farm products across international frontiers.

Production, exportation, and domestic disappearance are quantitative phenomena described by numbers; as, for example, numbers of bushels, barrels, or other units of weight or measure. For that reason, whatever shifts take place in the relationships among these quantities from year to year are reflected by the numerical relationships among the figures that express the quantities of wheat produced, or exported, or that have disappeared. Whenever a distinct or even approximate relationship can be shown, it is a help in analyzing the situation arising out of that relationship if the mathematical expression which describes it is available (*11*).

Domestic disappearance of wheat is the result chiefly of its utilization as human food or as seed, although a variable quantity is always stored. The quantity of seed used from the crop of any given year depends upon the area planted for the crop of the succeeding season. The quantity consumed as human food depends chiefly upon the number of inhabitants or consuming units within the country during the crop year. Usually there is little or no direct relationship between the annual fluctuations in these two groups of factors affecting disappearance of wheat. It has therefore been deemed expedient to consider the relationships of production, exportation, and disappearance from the viewpoint of net production; that is, production less seed (as noted above), in its relations to net exports and consequently to net disappearance. The human element can, also, be taken into numerical considerations and, therefore, the relation of per capita net production (P) to per capita net exports (E) and to per capita net disappearance (D), will be analyzed, in which $P-E=D$.

The relationships that existed among production, export, and disappearance of wheat in the old Kingdom of Hungary during the five years 1909–10 to 1913–14 will be briefly discussed as a background against which to picture the changes which have taken place in the situation following the World War. The figures representing per capita net production and per capita net disappearance for each year of the pre-war period are given in columns 2 and 3 of Table 11.

TABLE 11.—*Wheat: Per capita net production and per capita net disappearance in the old Kingdom of Hungary, 1909–10 to 1913–14*

Crop year	Per capita net production P	Per capita net disappearance D	PD	P^2	D^2
	Bushels	*Bushels*	*Bushels*	*Bushels*	*Bushels*
1909–10	4.73	4.13	19.5349	22.3729	17.0569
1910–11	7.41	5.11	37.8651	54.9081	26.1121
1911–12	7.72	5.11	39.4492	59.5984	26.1121
1912–13	7.54	5.07	38.2278	56.8516	25.7049
1913–14	6.63	4.68	31.0284	43.9569	21.9024
Total (Σ)	34.03	24.10	166.1054	237.6879	116.8884

A casual inspection of the figures under P and D, in Table 11, reveals a relationship between these two sets of variables. In general a year of low production (as in 1909) was associated with a 12-month period of low disappearance, and the year of maximum production (1911) was associated with 12 months during which disappearance was also maximum.

These numbers have been plotted in the scatter diagram, Figure 2, each dot representing the relation between per capita net production and per capita net disappearance. It is evident from this diagram that, in general, the crop years in which production was successively greater than in 1909 were associated with 12-month periods during which disappearance was successively greater than that during the 12 months August 1, 1909, to July 31, 1910.

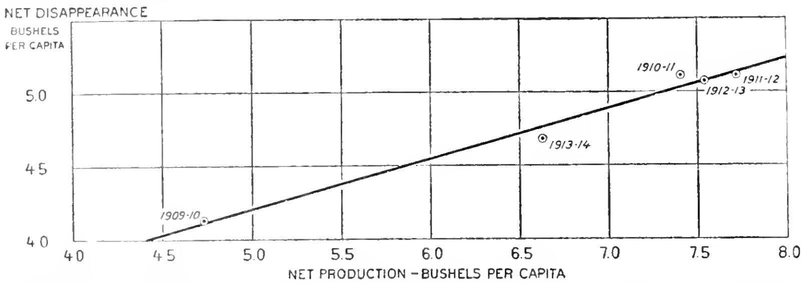

FIGURE 2.—RELATION BETWEEN PER CAPITA NET PRODUCTION AND PER CAPITA NET DISAPPEARANCE OF WHEAT IN THE OLD KINGDOM OF HUNGARY 1909-10 TO 1913-14

Before the World War, the fluctuations in per capita disappearance of wheat in the old Kingdom of Hungary bore a close relationship to fluctuations in production. The trend of this relationship is apparently a straight line.

If the Hungarian people had consumed as food, feed, or seed, or had stored or caused to disappear in some other manner all of the crop each succeeding year so that there was no wheat exported, the ratio of variation between disappearance and production would have been 1 to 1 and every point on a scatter diagram picturing the situation of that year would have been located in a straight line with a slope of 45°. Before the World War, the export organizations of the old Kingdom of Hungary shipped abroad a greater or less quantity of wheat as grain and flour depending upon the availability of the product and the margin of profit involved. This varying export tended to produce a relationship between disappearance and production not in the ratio of 1 to 1 but in the ratio of something less than 1 to 1. During the pre-war period, this relationship was analogous to a trend which apparently (fig. 2) can be represented by a straight line. Such a straight line could be fitted by inspection, but a more accurate result will be obtained if this line is fitted to the points on the scatter diagram by a modification of the method of least squares that brings out the average correlative relationship between the two sets of variables (P) and (D).

This calls for a solution of the following normal equations, which can be solved by substituting numerical values derived from the data as arranged in Table 11:

$$\Sigma\ (D) = na + b\Sigma\ (P)$$

$$\Sigma\ (DP) = a\Sigma\ (P) + b\Sigma\ (P^2)$$ [24]

[24] The reader is referred to (*11, pp. 366, 400*) for the discussion of principles.

Substituting gives

$$24.10 = 5a + 34.03b$$

$$166.1054 = 34.03a + 237.6879b$$

Solving,

$$a = 2.49$$

$$b = 0.342$$

The required equation is

$$D' = bP + a$$

$$D' = 0.342P + 2.49$$

The estimated per capita net disappearance under average conditions (D') associated with the production of each crop year in the old Kindgom of Hungary during the period 1909–10 to 1913–14 is given in column 4 in Table 12. These values for D' all fall in the straight line of average relationship plotted in Figure 2.

TABLE 12.—*Wheat: Estimated per capita net disappearance under average conditions contrasted with observed per capita net disappearance in the old Kingdom of Hungary, 1909–10 to 1913–14*

Crop year	Per capita net production	Production multiplied by ratio of variation	Estimated per capita net disappearance under average conditions	Observed per capita net disappearance	Difference between estimated and observed	$(D-D')^2$
	P	bP	$bP+a$[1]$=D'$	D	$D-D'$	
	Bushels	*Bushels*	*Bushels*	*Bushels*	*Bushel*	*Bushel*
1909–10	4.73	1.62	4.11	4.13	+0.02	0.0004
1910–11	7.41	1.54	5.03	5.11	+.08	.0064
1911–12	7.72	2.64	5.13	5.11	−.02	.0004
1912–13	7.54	2.58	5.07	5.07	.00	.0000
1913–14	6.63	2.27	4.76	4.68	−.08	.0064
Total (Σ)						.0136

[1] a is an algebraically negative quantity in this case.

If the relationship had been perfect, the observed disappearance associated with each crop year would also lie on the line of average relationship, and the equation could be used as an accurate instrument for determining the disappearance that would be associated with the production of any given year. But the observed disappearances are scattered or dispersed more or less above and below the line of estimated disappearances or the line of average relationship. Confidence in the accuracy with which the equation describes the relationship between disappearance and production for this particular period of years depends upon the amount of this scattering or dispersion, expressed as an average, which may be called the standard error of estimate, represented by the symbol S.

In computing S, we must know the normal value of D' (as given in column 4 of Table 12), which corresponds with the production of each crop year, P. The difference between the actually observed per capita net disappearance D and the normally to be expected disappearance under average conditions $(D-D')$ may then be determined. The root-mean-square of these deviations $\pm\sqrt{\frac{\Sigma(D-D')^2}{n}}$ is the required measure of dispersion.

Substituting gives

$$S=\pm\sqrt{\frac{0.0136}{5}}$$

$$S=\pm 0.052154$$

This means, if the distribution of observed disappearance is normal, that about 68 per cent of all cases will range within a vertical distance equivalent to 0.052 bushel above or below the line of average relationship, about 95 per cent will fall within a range of $\pm\ 2\ S$ (in this case ± 0.104 bushels), and 99 per cent will fall within a range of $\pm 3\ S$ (in this case ± 0.156 bushels (*11*)).

During the pre-war period, the population of the old Kingdom of Hungary averaged 21,050,000, whose wheat requirement, as measured by statistical disappearance, averaged 101,476,000 bushels. If the average relationship, outlined above, had been employed to estimate disappearance this estimate would be expected to approximate the calculated disappearance within a range of $\pm$ 3,300,000 bushels more or less or within 3.3 per cent in 99 cases out of 100. In 95 per cent of all cases, the range would probably have been about $\pm$2,200,000 bushels or 2.2 per cent; whereas, in about two-thirds of all cases, the range would have been about $\pm$1,100,000 bushels or 1.1 per cent. The maximum difference between estimated and observed pre-war disappearance (Table 12, column 5) was ± 0.08 bushel per capita; which was averagely equivalent to 1,684,000 bushels or 1.7 per cent.

The pre-war export trade in wheat in Hungary was even better organized than the domestic sale of flour and bread, and for that reason, as indicated in Table 13; and in Figure 3, there was a close relationship between production and export. As a rule the Hungarian people consumed more wheat in years of high production than averagely customary; but they also exported more. In years of less than average production they consumed and exported less than an average amount of wheat.

TABLE 13.—*Wheat: Per capita net production and per capita net export in the old Kingdom of Hungary, 1909–10 to 1913–14*

Crop year	Per capita net production P	Per capita net export E	EP	P^2	E^2
	Bushels	*Bushels*	*Bushels*	*Bushels*	*Bushels*
1909–10	4.73	0.60	2.8380	22.3729	0.3600
1910–11	7.41	2.30	17.0130	54.9081	5.2900
1911–12	7.72	2.61	20.1492	59.5984	6.8121
1912–13	7.54	2.47	18.6238	56.8516	6.1009
1913–14	6.63	1.95	12.9285	43.9569	3.8025
Total (Σ)	34.03	9.93	71.5825	237.6879	22.3655

The normal equations descriptive of the relationship of production to export are the same as those pertaining to production and disappearance, except that E is substituted for D, thus:

$$\Sigma(E) = na + b\Sigma(P)$$

$$\Sigma(EP) = a\Sigma(P) + b\Sigma(P^2)$$

Substituting values from Table 13 gives

$$9.93 = 5a + 34.03b$$

$$71.5825 = 34.03a + 237.6879b$$

$$a = -2.49$$

$$b = 0.658$$

$$E' = 0.658P - 2.49$$

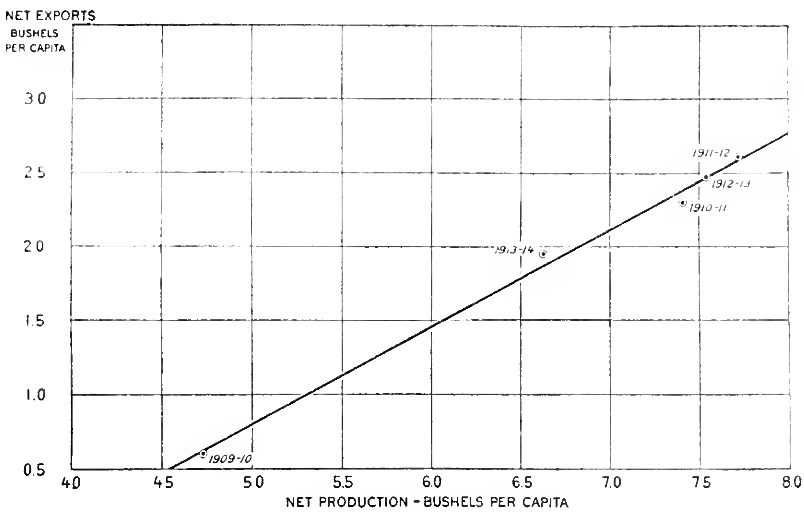

FIGURE 3.—RELATION BETWEEN PER CAPITA NET PRODUCTION AND PER CAPITA NET EXPORTS OF WHEAT IN THE OLD KINGDOM OF HUNGARY 1909-1910 TO 1913-14

Before the World War, fluctuations in per capita net exports from the old Kingdom of Hungary tended to bear as close or casual relationship to fluctuations in production, as did the fluctuations in per capita net disappearance. (Fig. 2.)

The estimated per capita net export under average conditions (E') coincident with the production of each crop year in the old Kingdom of Hungary during the period 1909–10 to 1913–14 is given in column 4 in Table 14. These values for E' all fall in the straight line of average relationship plotted in Figure 3.

TABLE 14.—*Wheat: Estimated per capita net export under average conditions contrasted with observed per capita net disappearance in the old Kingdom of Hungary, 1909–10 to 1913–14*

Crop year	Per capita net production	Production multiplied by ratio of variation	Estimated per capita net export under average conditions	Observed per capita net export	Difference between estimated and observed	$(E-E')^2$
	P	bP	$bP+a$[1]$=E'$	E	$E-E'$	
	Bushels	*Bushels*	*Bushels*	*Bushels*	*Bushel*	*Bushel*
1909–10	4.73	3.11	0.62	0.60	−0.02	0.0004
1910–11	7.41	4.87	2.38	2.30	−.08	.0064
1911–12	7.72	5.08	2.59	2.61	+.02	.0004
1912–13	7.54	4.96	2.47	2.47	.00	.0000
1913–14	6.63	4.36	1.87	1.95	+.08	.0064
Total (Σ)						.0136

[1] *a* is an algebraically negative quantity in this case.

Substituting in the equation $S=\pm\sqrt{\frac{\Sigma(E-E')^2}{n}}$ gives:

$$S=\pm\sqrt{\frac{0.0136}{5}}$$

$$S=\pm 0.052$$

The standard error of estimate in the case of exports is identical with that in the case of disappearance in the old Kingdom of Hungary before the World War. As in the case of per capita net disappearance, this indicates that in about two-thirds of all cases, under pre-war conditions, per capita net export could be expected to range about 1,100,000 bushels above or below that estimated by the equations here given. Before the World War the old Kingdom exported 41,901,000 bushels of wheat as grain and flour, and the range of 1,100,000 bushels represents 2.6 per cent of the average export. The maximum difference between estimated and observed pre-war exports (Table 14, column 5) was ±0.08 bushel per capita; which was an equivalent to 1,684,000 bushels, or 4 per cent.

If history repeated itself, this sort of analysis of the relations of production to disappearance and exportation would predict with mathematical precision the disposition of the wheat crop to be expected, on an average, for any current year. Sometimes history does repeat itself, expecially during a period of settled food habits and commercial procedure. In such countries as pre-war Hungary, France, and Rumania, conditions of production and disappearance ranged within rather well-defined limits for several years in succession so that during those years an analysis of data pertaining to production, international trade, and disappearance, similar to that outlined above, might give dependable results.

But changed conditions are followed by changes in the relationships of disappearance to production so that these relationships may become strikingly different from those that have been typical of preceding periods. The upheaval of the World War has, naturally, been followed by fundamental changes in the relationships of production to the ultimate disposition of the crop.

In the first place, Hungary was partitioned; then the country passed through a governmental crisis, followed by a series of financial disturbances. The Government even undertook to supervise the grain trade and a Ministry of Public Provisioning undertook to regulate the manner in which the population nourished itself. However, when the averages of per capita production, exportation, and disappearance in Hungary, present boundary, for the five years 1922–23 to 1926–27 (Table 15) are compared with those of the old Kingdom for the 5-year period 1909–10 to 1913–14, the differences are not great. The per capita net production of wheat in the old Kingdom before the World War was 6.81 bushels, as compared with the post-war average for residual Hungary of 6.49 bushels. The pre-war per capita net exports averaged 1.99, as compared with 1.82 for the post-war period. Per capita net diappearance of the old Kingdom averaged 4.82 bushels during 1909–10 to 1913–14, as compared with an average of 4.67 bushels during 1922–23 to 1926–27 in present-day Hungary.

TABLE 15.—*Wheat: Per capita net production, export and disappearance, old Kingdom of Hungary, 1909–10 to 1913–14, and Hungary present boundary, 1920–21 to 1926–27*

Crop year	Per capita net		
	Production *P*	Export *E*	Disappearance *D*
	Bushels	*Bushels*	*Bushels*
Old Kingdom of Hungary:			
1909–10	4.73	0.60	4.13
1910–11	7.41	2.30	5.11
1911–12	7.72	2.61	5.11
1912–13	7.54	2.47	5.07
1913–14	6.63	1.95	4.68
Average 1909–10 to 1913–14	6.81	1.99	4.82
Hungary present boundary:			
1920–21	3.72	0.01	3.73
1921–22	5.30	1.13	4.17
1922–23	5.57	0.61	4.96
1923–24	7.03	2.00	5.03
1924–25	5.02	1.60	3.42
1925–26	7.31	2.33	4.98
1926–27	7.52	2.56	4.96
Average 1922–23 to 1926–27	6.49	1.82	4.67

A superficial inspection of the figures in Table 15 reveals a close relationship between production (*P*) and export (*E*), in Hungary, present boundary, whereas there is apparently little relationship between (*P*) and (*D*). The crop year 1924–25 is an exception. In 1922, the Hungarian Government took direct charge of exportations, and by 1923 the Government's buying organization was perfected to ship the largest possible quantity of wheat and flour out of the country. Although the crop of the year 1924–25 was very poor, the Government's buying organization purchased and exported nearly the same quantity of wheat and flour that they shipped abroad during 1923–24, leaving the nation to go on short rations, as there had also been a sharp falling off in the production of rye. This created an abnormal situation in the relationships of disappearance and export to the production of that crop year.

Under the conditions prevailing in Hungary during the four seasons 1922–23, 1923–24, 1925–26, and 1926–27 the Government, and those organizations that operated under governmental regulations, tended to leave within the country for domestic utilization about the same minimum quantities of wheat and flour each season and exported as much of the surplus as possible so that this exported quantity was necessarily very nearly proportional to the production.

The postwar trend in disappearance and export is therefore best described by the relationships of this group of variables if the low disappearance under the abnormal conditions of 1924–25 is excluded. The relationships between production and export for the four remaining years are indicated in Table 16.

TABLE 16.—*Wheat: Per capita net production and per capita net export in Hungary, present boundary, 1922–23, 1923–24, 1925–26, 1926–27*

Crop year	Per capita net production P	Per capita net exports E	EP	P^2	E^2
	Bushels	*Bushels*	*Bushels*	*Bushels*	*Bushels*
1922–23	5.57	0.61	3.3977	31.0249	0.3721
1923–24	7.03	2.00	14.0600	49.4209	4.0000
1925–26	7.31	2.33	17.0323	53.4361	5.4289
1926–27	7.52	2.56	19.2512	56.5504	6.5536
Total (Σ)	27.43	7.50	53.7412	190.4323	16.3546

If the totals of the columns in Table 16 are substituted in the normal equations, given on page 37, it is seen that:

$$E' = 0.9909\ P - 4.92$$

This means that, during the four crop years 1922–23, 1923–24, 1925–26, and 1926–27, a given per capita net production (P) was accompanied, on an average, by a per capita net export equivalent to 99.09 per cent of (P) minus 4.92 bushels.

The estimated per capita net export of wheat under average conditions (E') coincident with the per capita net production of each of the four crop years under consideration is given in column 4 in Table 17. These values for (E') all fall in the straight line of average relationship plotted in Figure 4.

TABLE 17.—*Wheat: Estimated per capita net export under average conditions contrasted with observed per capita net export in Hungary, present boundary, 1922–23, 1923–24, 1925–26, and 1926–27*

Crop year	Per capita net production P	Production multiplied by ratio of variation bP	Estimated per capita net export under average conditions $bP+a^1=E'$	Observed per capita net export E	Difference between estimated and observed $E-E'$	$(E-E')^2$
	Bushels	*Bushels*	*Bushels*	*Bushels*	*Bushel*	*Bushel*
1922–23	5.57	5.52	0.60	0.61	+0.01	0.0001
1923–24	7.03	6.97	2.05	2.00	−.05	.0025
1925–26	7.31	7.24	2.32	2.33	+.01	.0001
1926–27	7.52	7.45	2.53	2.56	+.03	.0009
Total (Σ)						.0036

[1] a is an algebraically negative quantity in this case.

The standard error of estimate is found by substituting in the equation $S = \pm\sqrt{\frac{\Sigma\ (E-E')^2}{n}}$ gives:

$$S = \pm\sqrt{\frac{0.0036}{4}}$$

$$S = \pm 0.03$$

This means that in about two-thirds of all cases in which the average conditions of these four years prevail, the export, estimated by the equation $E' = 0.9909\ P - 4.92$, should approximate the observed export—within a range of 0.03 bushel per capita.

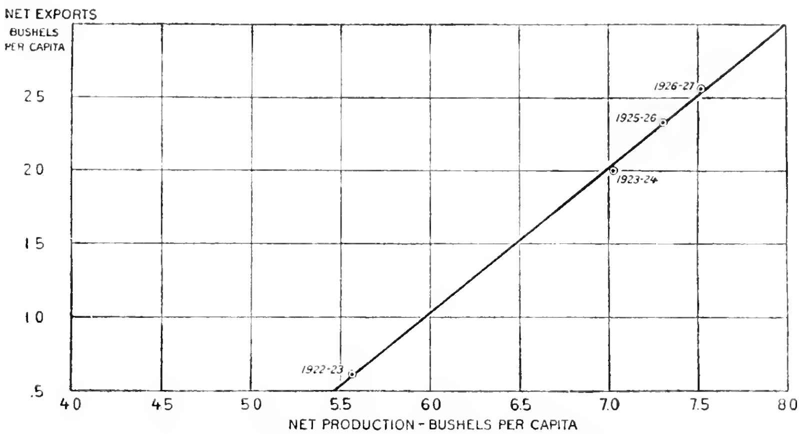

FIGURE 4.—RELATION BETWEEN PER CAPITA NET PRODUCTION AND PER CAPITA NET EXPORTS OF WHEAT IN RESIDUAL HUNGARY, 1922-23, 1923-24, 1925-26, AND 1926-27

During the four years, 1922–23, 1923–24, 1925–26, and 1926–27 per capita net disappearance in residual Hungary tended to remain of a very nearly constant level so that the fluctuations in per capita net exports tended to bear an almost direct proportional relationship to the fluctuations in production.

If the conditions prevailing during the season 1927–28 did not differ materially from the average conditions that prevailed during this 4-year period, there would be a chance of 68 to 100 that the relations between production and exportation during 1927–28 would be similar within the margin of ± 0.03 bushel per capita to the average relations that existed between production and exportation during the period. Any estimate based upon the above probability could be expected to hold true only in so far as actual conditions of the crop year 1927–28 approximated average conditions. A material change in any of the factors involved would produce a change in result, causing the actual per capita net exports to deviate from the calculated net exports or expectancy by a margin greater than the calculated value of $S = \pm 0.03$ bushel per capita, as was the case in 1923–24.

The net production of wheat in Hungary, 1927, was 7.65 bushels per capita. The estimated per capita net export under average conditions for the crop year 1927–28 is found by substituting in the normal equation above; which gives

$$E' = 7.65 \times 0.9909 - 4.92$$

$$E' = 2.66$$

The probable per capita net export under average conditions for the year 1927–28 is, thus, estimated to be 2.66 bushels. Multiplying 8,520,000, the estimated population of Hungary for 1927–28, by 2.66 bushels gives 22,663,000 bushels as the net export to be expected during 1927–28 if average conditions prevailed.

Preliminary reports for the 12 months ended July 31, 1928, indicate net exports of wheat and flour from residual Hungary, in terms of wheat, to be approximately 21,491,000 bushels or 1,172,000 bushels below the estimated expectancy under average conditions.

Under the average conditions of the four years 1922–23, 1923–24, 1925–26, and 1926–27 there was a probability of about 68 to 100 that the observed export would approximate the estimated export within a range of ±0.03 bushel per capita or ±256,000 bushels. There was a probability of 95 to 100 that the range would fall within ±511,000 bushels and a probability of 99 to 100 that the range would be not greater than ±767,000 bushels.

The fact that the actual exports from Hungary during 1927–28 fluctuated 405,000 bushels below the lower level of expectancy is associated with the relative price levels in Hungary, Austria, and Czechoslovakia. This downward fluctuation is, also, associated with the shortage of the domestic rye crop and relatively high rye prices, which probably increased the domestic demand for wheat.

During 1926 the average price of domestic wheat in Budapest was equivalent to $1.51 per bushel, as compared with $1.57 in Vienna and $1.77 in Prague; and wheat moved up the Danube to Austria and Czechoslovakia. The average price relationships during 1927 were $1.52 in Budapest, $1.57 in Vienna, and $1.93 in Prague. The margin between the price of wheat in Hungary and that in the upper Danube States narrowed toward the close of the year and wheat moved more slowly toward Czechoslovakia and not at all toward Vienna, where, during the first three months of 1928, the average price was equivalent to $1.53 per bushel, as compared with $1.53 in Budapest. The price of wheat improved steadily during April, May, and June, but during these months Czechoslovakia offered a better price for rye on a weight basis than for wheat. Consequently an abnormal situation was created. The exports of rye greatly exceeded expectancy, whereas less wheat was exported than might have been expected from the increased production of 1927. At the same time domestic disappearance of wheat reached the highest point since the World War. Rye and wheat are so intimately associated in the dietary and trade of central Europe that the situations in wheat can not be described without taking into consideration the situation in rye.

TABLE 18.—*Wheat: Acreage and production in Hungary, 1877–1928*

Year	Hungary (proper)			Croatia and Slavonia			Total Hungary		
	Acreage	Production	Yield per acre	Acreage	Production	Yield per acre	Acreage	Production	Yield per acre
	1,000 acres	*1,000 bushels*	*Bushels*	*1,000 acres*	*1,000 bushels*	*Bushels*	*1,000 acres*	*1,000 bushels*	*Bushels*
Pre-war year:									
1877	5,972	[1] 76,910	12.88	-------	-------	-------	5,972	76,910	12.88
1878	6,185	[1] 108,619	17.56	-------	-------	-------	6,185	108,619	17.56
1879	6,091	[1] 52,217	8.57	-------	-------	-------	6,091	52,217	8.57
1880	5,958	[1] 79,325	13.31	-------	-------	-------	5,958	79,325	13.31
1881	6,262	[1] 88,897	14.20	-------	-------	-------	6,262	88,897	14.20
1882	6,163	[1] 131,757	21.38	-------	-------	-------	6,163	131,757	21.38
1883	6,437	[1] 90,548	14.07	-------	-------	-------	6,437	90,548	14.07
1884	6,798	[1] 107,217	15.77	-------	-------	-------	6,798	107,217	15.77
1885	6,773	114,735	16.94	400	5,324	13.31	7,173	120,059	16.74
1886	6,830	103,701	15.18	400	5,328	13.32	7,230	109,029	15.08
1887	6,862	147,161	21.45	415	5,346	12.88	7,277	152,507	30.96
1888	6,845	136,990	20.01	427	6,015	14.09	7,272	143,005	19.67
1889	7,193	94,313	13.11	445	4,920	11.06	7,638	99,233	12.99
1890	7,361	149,318	20.29	465	6,790	14.60	7,826	156,108	19.95
1891	7,443	140,470	18.87	487	6,662	13.68	7,930	147,132	18.55
1892	7,571	143,773	18.99	516	7,139	13.84	8,087	150,912	18.66
1893	8,100	160,612	19.83	549	8,201	14.94	8,649	168,813	19.52
1894	7,917	145,588	18.39	566	8,837	15.61	8,483	154,425	18.20
1895	7,742	163,291	21.09	561	8,583	15.30	8,303	171,874	20.70
1896	7,724	151,643	19.63	586	9,575	16.34	8,310	161,218	19.40
1897	6,869	81,074	11.80	576	6,140	10.66	7,445	87,214	11.71
1898	7,554	128,227	16.97	605	11,409	18.86	8,159	139,636	17.11
1899	7,803	141,285	18.11	635	9,013	14.19	8,438	150,298	17.81
1900	8,142	141,201	17.34	665	11,034	16.59	8,807	152,235	17.29
1901	8,196	123,935	15.12	670	10,692	15.96	8,866	134,627	15.18
1902	8,263	170,882	20.68	687	12,019	17.49	8,950	182,901	20.44
1903	8,513	161,954	19.02	714	14,664	20.54	9,227	176,618	19.14
1904	8,401	137,078	16.32	729	9,840	13.50	9,130	146,918	16.09
1905	8,443	157,511	18.66	754	13,077	17.34	9,197	170,588	18.55
1906	8,784	197,107	22.47	736	10,351	14.06	9,520	207,758	21.82
1907	8,069	120,507	14.93	708	10,170	14.36	8,777	130,677	14.89
1908	8,715	152,204	17.46	759	13,220	17.42	9,474	165,424	17.46
1909	8,036	113,353	14.11	763	11,662	15.28	8,799	125,015	14.21
1910	8,584	169,703	19.77	791	11,435	14.46	9,375	181,138	19.32
1911	8,354	174,891	20.94	808	15,190	18.80	9,162	190,081	20.75
1912	8,748	173,326	19.81	827	11,313	13.68	9,575	184,639	19.28
1913	7,700	151,349	19.66	833	15,998	19.21	8,533	167,347	19.61
War years:									
1914	8,016	105,240	13.13	846	12,537	14.82	8,862	117,777	13.29
1915	8,081	148,755	18.41	798	8,892	11.14	8,879	157,647	17.76
1916	7,628	112,253	14.72	764	8,209	10.74	8,392	120,462	14.35
1917	7,826	123,231	15.75	(2)	(2)	-------	7,826	123,231	15.75
1918	7,678	95,095	12.39	(2)	(2)	-------	7,678	95,095	12.39
Post-war years:									
1919	(3)	(3)	(3)	(2)	(2)	-------	(3)	(3)	(3)
1920	2,662	37,927	14.25	(2)	(2)	-------	2,662	37,927	14.25
1921	2,888	52,715	18.25	(2)	(2)	-------	2,888	52,715	18.25
1922	3,522	54,729	15.54	(2)	(2)	-------	3,522	54,729	15.54
1923	3,293	67,705	20.56	(2)	(2)	-------	3,293	67,705	20.56
1924	3,499	51,568	14.74	(2)	(2)	-------	3,499	51,568	14.74
1925	3,524	71,675	20.34	(2)	(2)	-------	3,524	71,675	20.34
1926	3,706	74,908	20.21	(2)	(2)	-------	3,706	74,908	20.21
1927	4,021	76,933	19.13	(2)	(2)	-------	4,021	76,933	19.13
1928	4,133	92,037	22.27	(2)	(2)	-------	4,133	92,037	22.27

Acreage and production:
1877–1896 from Das Getreide in Weltverkehr, Austria 1900: 50–53.
1897–1904 from Das Getreide in Weltverkehr, Austria 1905: 20–21.
1905–1906 from Das Getreide in Weltverkehr, Austria 1909: 16–17.
1907–1908 from Magyar Statisztikai Évkön. 1910: 100–101.
1909–1912 from Magyar Statisztikai Évkön. 1913: 87–88.
1913–1915 from Magyar Statisztikai Évkön. 1915: 86–87.
1916–1918 from Ann. Statis. Hongrois 1916, 1917, 1918: 40–44, 47–52.
1920 from Ann. Statis. Hongrois 1919–1922: 56, 60.
1921–1928 from official records of U. S. Department of Agriculture, Bureau of Agricultural Economics.

[1] Winchester bushels converted from hectoliters. [2] Ceded to Yugoslavia. [3] Not available.

RYE

Before the World War the territories comprised within the present boundaries of Hungary seeded 1,608,000 acres of rye. In 1921, there were only 1,341,000 acres under rye, since which time acreage increased to 1,729,000 acres in 1926, falling off to 1,641,000 in 1928.

Post-war yields per acre have averaged (1922–1926) about 17.06 bushels, as compared with an average of 19.51 bushels during 1909–1913. The year 1927 was not favorable to rye production, and the yield per acre fell off to 13.5 bushels.

Net production, except for the years 1925 and 1928, have not come up to the pre-war average. On the other hand, per capita disappearance has averaged about one-half bushel greater than was normal before the World War. These varying factors have resulted in a falling off in the exportable surplus. As indicated in Table 19, the exports in 1925–26, the season of post-war maximum production were only 6,950,000 bushels, or about 44 per cent of the surplus estimated to have been available for export before the war. The exportation of rye from Hungary has, however, been somewhat irregular, as evidenced by the fact that although the production of 1926 was somewhat lower than that of 1925 the net exports of 1926–27 were over 3,000,000 bushels greater than those during the preceding season.

TABLE 19.—*Rye: Statistical balances of Hungary, old boundary, 1904–5 to 1913–14; new boundary, average 1909–1913, and annual, 1920–21 to 1928–29*

Crop year	Acreage [1]	Seed [2]	Production		Disappearance		Net exports [5]
			Gross [1]	Net [3]	Statistical	Per capita [4]	
	1,000 acres	*1,000 bushels*	*1,000 bushels*	*1,000 bushels*	*1,000 bushels*	*Bushels*	*1,000 bushels*
Former boundary:							
1904–5	2,778	8,556	45,918	37,279	--------	--------	[6] 6,871
1905–6	2,805	8,639	53,079	44,403	--------	--------	[6] 10,909
1906–7	2,817	8,676	53,879	45,772	30,500	1.51	15,272
1907–8	2,632	8,107	41,581	33,111	21,092	1.03	12,019
1908–9	2,750	8,470	47,705	39,518	28,868	1.40	10,650
Average 1906–7 to 1908–9	2,756	--------	48,432	40,018	26,820	1.31	12,647
1909–10	2,658	8,187	47,246	38,588	27,618	1.33	10,970
1910–11	2,810	8,658	51,792	43,374	28,302	1.36	15,072
1911–12	2,733	8,118	50,328	40,649	25,532	1.21	16,117
1912–13	2,818	8,679	53,194	44,804	32,672	1.54	12,132
1913–14	2,724	8,390	52,697	43,891	28,136	1.32	15,755
Average 1909–10 to 1913–14	2,749	--------	51,051	42,461	28,452	1.35	14,009
New boundary:							
Estimated average 1909–1913	[7] 1,608	4,888	[7] 31,377	26,489	10,663	[8] 1.40	[9] 15,826
1920–21	1,175	4,484	20,248	16,171	15,324	1.92	[10] 847
1921–22	1,341	4,077	23,177	18,121	15,698	1.95	[10] 2,423
1922–23	1,663	5,056	25,147	20,222	17,650	2.17	[10] 2,572
1923–24	1,620	4,925	31,271	26,294	20,440	2.49	[10] 5,854
1924–25	1,638	4,980	22,103	16,938	11,416	1.38	[11] 5,522
1925–26	1,699	5,165	32,526	27,270	20,320	2.43	[11] 6,950
1926–27	1,729	5,256	31,416	26,379	16,139	1.91	[11] 10,240
1927–28	1,657	5,037	22,365	17,376	12,905	1.51	[11] 4,471
1928–29	1,641	4,989	32,528	27,539	--------	--------	--------

[1] Acreage and production from official records of U. S. Department of Agriculture, Bureau of Agricultural Economics.

[2] 3.08 bushels per acre for old boundary and 3.04 bushels per acre for new boundary (*10 p. 16*).

[3] Seed for acreage the following year subtracted from production for stated year, except average 1909–1913 and annual 1928–29.

[4] For populations see Table 8.

[5] Years beginning Aug. 1, 1904–5 to 1913–14 from Ann. Internatl. Statis. Agr. 1913–14: 129–131.

[6] Does not include rye flour.

[7] Acreage and production calculated from Magyar Statisztikai Évkön. 1909–1913.

[8] Includes Budapest. The estimated per capita consumption in Budapest was 1.34 bushels per year. The rural population is estimated to have consumed about 1.41 bushels of rye.

[9] Surplus.

[10] Net exports of rye for years beginning Aug. 1 and net exports of rye flour estimated by taking the average of the two calendar years from Internatl. Yearbook Agr. Statis., 1923, 1924–25 and 1926–27.

[11] Net exports of rye for years beginning Aug. 1 and net exports of rye flour for years beginning July 1 from Internatl. Yearbook Agr. Statis. 1927–28.

Although the acreage of rye, since 1922, has been in excess of the pre-war average of 1,608,000 acres, it is improbable that there will be any marked expansion above the 1926 area of 1,729,000 acres. Rye acreage in Hungary has probably been slightly affected by the land reform but probably more by the pressure brought to bear by the Ministry of Public Provisioning to increase the use of rye as a wheat substitute in making bread. It is probable that some of the present rye acreage is marginal so that when governmental stimulus is removed acreage may decrease.

INTERNATIONAL TRADE IN RYE

The old Kingdom of Hungary exported (net) on the average 14,009,000 bushels of rye as grain and flour during the 5-year period ended July 31, 1914. During this period the rye and rye-flour exports from the territory now constituting Hungary are estimated to have been equivalent to 15,826,000 bushels. A part of this surplus produced in the central part of the old Kingdom was shipped to deficit areas of Crotia and Slavonia, and the balance went chiefly to cover the deficits of present-day Austria and the northwestern districts of present day Czechoslovakia.

Both before and since the World War, the export of rye from Hungary fluctuated widely, corresponding with fluctuations in production. By far the greater part of Hungary's rye exports are in the form of grain. (Table 20.)

TABLE 20.—*Rye and rye flour: Imports and exports of Hungary, 1904–5 to 1913–14 and 1919–20 to 1927–28*

Year	Rye		Rye flour	
	Imports	Exports	Imports	Exports
Pre-war years:	*Bushels*	*Bushels*	*Barrels*	*Barrels*
1904–5	98, 172	6, 968, 918	-	-
1905–6	20, 479	10, 929, 860	-	-
1906–7	12, 354	12, 427, 039	11, 354	487, 554
1907–8	19, 822	9, 477, 591	9, 698	436, 540
1908–9	16, 058	7, 991, 006	12, 225	458, 063
1909–10	24, 609	9, 112, 234	20, 069	333, 812
1910–11	16, 609	12, 580, 156	20, 910	438, 909
1911–12	20, 637	12, 688, 504	20, 107	595, 026
1912–13	18, 133	9, 259, 883	17, 689	499, 351
1913–14	23, 030	11, 339, 966	20, 711	760, 445
Post-war years:				
1919–20	-	5, 830	-	1, 792
1920–21	-	-	-	-
1921–22	7, 118	34, 329	-	-
1922–23	1, 559	20, 983	-	-
1923–24	409	3, 804, 163	-	-
1924–25	4, 295	4, 055, 885	[1] 1, 491	[1] 246, 552
1925–26	228	6, 079, 196	[1] 66	[1] 145, 293
1926–27	921	9, 570, 224	[1] 87	[1] 111, 799
1927–28	1, 527	3, 870, 597	[1] 26	[1] 100, 307

1904–5 to 1913–14 from Ann. Internatl. Statis. Agr. 1913–14.
1919–20 and 1920–21 from Ann. Internatl. Statis. Agr. 1922–23.
1921–22 from Ann. Internatl. Statis. Agr. 1924–25.
1922–23 and 1923–24 from Ann. Internatl. Statis. Agr. 1925–26.
1924–25 to 1927–28 from Ann. Internatl. Statis. Agr. 1927–28.
These data can not be considered comparable owing to frontier alterations during the period under review.

[1] Fiscal year July 1 to June 30.

During the calendar year 1926, 51 per cent of all rye exports went to Austria, 25 per cent to Czechoslovakia, 13 per cent to Germany, 5 per cent to Italy, and the remaining 6 per cent went to other countries including Poland, Belgium, Holland, France, and Switzerland.

During the calendar year 1927, the following quantities of rye were exported: To Austria, 2,942,000 bushels; to Czechoslovakia, 1,785,000 bushels; to Poland, 348,000 bushels; to Germany, 267,000 bushels; to Italy, 66,000 bushels.

THE RELATION OF PRODUCTION AND DISAPPEARANCE TO THE EXPORT OF RYE

As in the case of the wheat industry, the World War produced profound changes in the relationships of production and disappearance to the export of rye. The treaty of Trianon segregated the eastern and southern districts, in which both production and consumption of rye were low. Hungary produced 3.02 bushels of rye per capita, during the 5-year period 1922–23 to 1926–27, as compared with 2.02 bushels in the old Kingdom before the World War. Disappearance averaged 2.25 bushels per capita during these post-war years, as compared with the pre-war average disappearance of 1.35 bushels. Net exports averaged one-tenth of a bushel per capita greater in Hungary during 1922-23 to 1926–27 than in the old Kingdom during 1909–10 to 1913–14. (Table 21.)

TABLE 21.—*Rye: Per capita net production, export, and disappearance, average old Kingdom of Hungary, 1909–10 to 1913–14 and annual, Hungary present boundary, 1920–21 to 1926–27*

Crop year	Per capita net		
	Production P	Export E	Disappearance D
Old Kingdom of Hungary:	*Bushels*	*Bushels*	*Bushels*
1909–10	1.86	0.53	1.33
1910–11	2.08	.72	1.36
1911–12	1.98	.77	1.21
1912–13	2.11	.57	1.54
1913–14	2.05	.73	1.32
Average 1909–10 to 1913–14	2.02	.67	1.35
Hungary, present boundary:			
1920–21	2.03	.11	1.92
1921–22	2.25	.30	1.95
1922–23	2.48	.31	2.17
1923–24	3.20	.71	2.49
1924–25	2.05	.67	1.38
1925–26	3.26	.83	2.43
1926–27	3.12	1.21	1.91
Average 1922–23 to 1926–27	3.02	.77	2.25

A superficial inspection of the postwar figures in Table 21 reveals a closer annual relationship between fluctuations in production (P) and export (E) than between those of (P) and (D). In discussing the case of wheat, the data of the very unusual crop-year 1924–25 was eliminated. In the case of rye, disappearance dropped to 1.38 bushels per capita during 1924–25. For this reason and for purposes of comparison with the wheat situation, the postwar trend in disappearance and export is considered to be best described by the relationships of the years 1922–23, 1923–24, 1925–26, and 1926–27 as indicated in Table 22.

TABLE 22.—*Rye: Per capita net production and per capita net export in Hungary, present boundary, 1922–23, 1923–24, 1925–26, and 1926–27*

Crop year	Per capita net production P	Per capita net export E	EP	P^2	E^2
	Bushels	*Bushels*	*Bushels*	*Bushels*	*Bushels*
1922–23	2.48	0.31	0.7688	6.1504	0.0961
1923–24	3.20	.71	2.2720	10.2400	.5041
1925–26	3.26	.83	2.7058	10.6276	.6889
1926–27	3.12	1.21	3.7752	9.7344	1.4641
Total (Σ)	12.06	3.06	9.5218	36.7524	2.7532

If the totals of the columns in Table 22 are substituted in the normal equations, given on page 37, it is found that:

$$E' = 0.7556\,P - 1.51$$

If this equation is used in estimating the per capita net export of rye under average conditions, the values for E' coincident with the per capita net production of each of the 4-crop years as given in column 4 of Table 23 are obtained. These values for E' all fall in the straight line of average relationship plotted in Figure 5.

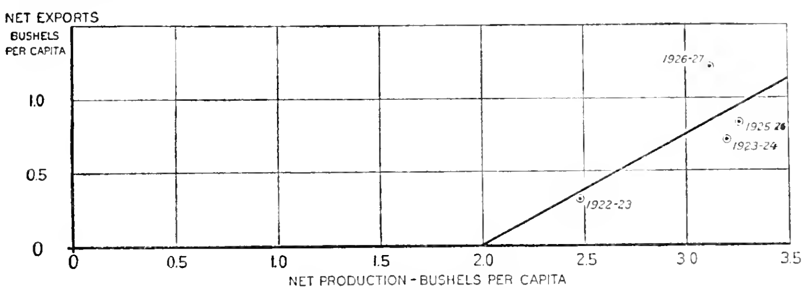

FIGURE 5.—RELATION BETWEEN PER CAPITA NET PRODUCTION AND PER CAPITA NET EXPORTS OF RYE IN RESIDUAL HUNGARY, 1922-23, 1923-24, 1925-26, AND 1926-27

The relationship of per capita net exports of rye from residual Hungary during the years 1922–23, 1923–24, 1925–26, and 1926–27 exhibited a trend relationship to production; but this relationship was not nearly as close as in the case of wheat. (Fig. 4.)

TABLE 23.—*Rye: Estimated per capita net export under average conditions contrasted with observed per capita net export in Hungary, present boundary, 1922–23, 1923–24, 1925–26, and 1926–27*

Crop year	Per capita net production P	Production multiplied by ratio of variation bP	Estimated per capita net export under average conditions $bP+a$[1]$=E'$	Observed per capita net export E	Difference between estimated and observed $E-E'$	$(E-E')^2$
	Bushels	*Bushels*	*Bushel*	*Bushels*	*Bushel*	*Bushel*
1922–23	2.48	1.87	0.36	0.31	−0.05	0.0025
1923–24	3.20	2.42	.91	.71	−.20	.0400
1925–26	3.26	2.46	.95	.83	−.12	.0144
1926–27	3.12	2.36	.85	1.21	+.36	.1296
Total (Σ)						.1865

[1] a is an algebraically negative quantity in this case.

The domestic disappearance of rye in Hungary has fluctuated more widely than has that of wheat. Consequently the relationship of production to export has not been as close as in the case of the major bread cereal. An inspection of the scatter diagram, Figure 5, shows a much greater dispersion of the annual observed rye exports about the line of average relationship than was the case with observed wheat exports. (Fig. 4.)

It is therefore to be expected that the value of the standard error of estimate, in the case of rye exports, will be greater than in the case of wheat exports.

Substituting in the equation $S=\pm\sqrt{\frac{\Sigma(E-E')^2}{n}}$ gives

$$S=\pm\sqrt{\frac{0.1865}{4}}$$

$$S=\pm 0.216$$

Another way of putting this is to say that there is not as close a correlation between production and exports of rye as between production and exports of wheat. The measure of correlation (r) between two variables as P and E can be expressed by the equation

$$r=\pm\sqrt{1-\frac{S^2}{\frac{\Sigma E^2}{n}-\left(\frac{\Sigma E}{n}\right)^2}}$$

Substituting in the case of rye gives:

$$r=\pm\sqrt{1-\frac{0.046625}{0.6883-0.585225}}$$

$$r=\pm 0.74$$

Substituting the value of S in the case of wheat (p. 41) and the values of $\frac{\Sigma E^2}{n}$ and $\left(\frac{\Sigma E}{n}\right)^2$, derived from Table 16 gives

$$r=\pm\sqrt{1-\frac{0.0009}{4.08865-3.51563}}$$

$$r=\pm 0.999$$

The lower correlation between rye production and rye export indicates that under average conditions each observed annual export (E) will not tend to approximate the corresponding estimated export (E') within as close a range as in the case of wheat.

The net production of rye in Hungary in 1927 was only 17,376,000 bushels, or 2.04 bushels per capita, as compared with a per capita net production of 3.12 bushels the previous season. The estimated per capita net export for the crop year 1927–28 that might have been expected under the average conditions of 1922–23, 1923–24, 1925–26, and 1926–27, is found by substituting in the normal equation as given on page 47, which gives $E' = 2.04 \times 0.7556 - 1.51$

$$E' = 0.03$$

The value of $S = \pm 0.216$ (the standard error of estimate) is 7.2 times as great as this estimated value $E' = 0.03$ (the probable export under average conditions). Even under average conditions, little dependence could be placed on this estimate of probable export. The situation that developed during 1927–28 was far from average.

The estimated per capita export of 0.03 bushel is equivalent to an estimated total net export of 256,000 bushels.[25]

Multiplying the error of estimate (± 0.216) by the 1927–28 estimated population indicates a probability of 68 in 100 that the actual export would be 1,840,000 bushels greater or less than the estimated; that is, international trade might range from an export of 2,096,000 bushels to an import of 1,584,000 bushels. The chances were 95 in 100 that international trade might range from an import of 3,425,000 bushels to an export of 3,937,000 bushels. This is a range of 7,300,000 bushels, which is greater than the net export of any crop year, except 1926–27.

Preliminary reports for the 12 months ended July 31, 1928, indicate that net exports of rye from Hungary were approximately 4,471,000 bushels. This export of 4,471,000 bushels of rye during a season when there was a rye shortage in many parts of the country was possible because of the peculiar location of the rye surplus-producing districts.

The chief rye surplus-producing regions in Hungary are the Comitat of Pest, comprising the light soils along the east bank of the Danube, and the northwestern comitates along the south bank of the Danube. (Fig. 6.) In years of high production it is very easy to concentrate and ship rye up the Danube to Austria and Czechoslovakia, and the grain-handling organizations of these regions are organized primarily to export grain rather than to cater to the domestic trade. It is also easier in years of generally low production to concentrate the rye of these townships along the Danube for export than to distribute it to the districts of rye shortage in eastern and southeastern Hungary. At such times, these deficit districts generally make up their rye shortage by consuming a greater than normal amount of wheat, particularly if wheat is relatively cheap. It is not customary in Hungary as in Germany to substitute potatoes for rye in making bread.

In April and May, 1927, disastrous frosts reduced the productivity of the rye crop, which was 28.8 per cent below that of 1926. The price situation in Hungary can not be analyzed completely on account of lack of data. However, during the second half of the calendar year 1927 prices rose from 27.52 pengös per quintal (122 cents per bushel) in August to 29.15 pengös (129 cents per bushel) in December. This rise was chiefly in response to home demand since there were relatively favorable harvests in Austria and Czechoslovakia and the foreign demand for Hungarian rye was apathetic. During the

[25] The estimated population for 1927–28 was 8,520,000.

early months of 1928 the price of rye in Hungary rapidly approached that of wheat, the price difference amounting to 5 to 6 per cent in

FIGURE 6.—AVERAGE PRODUCTION OF RYE, 1911-1915, BALANCED AGAINST DISAPPEARANCE

The numbers represent thousands of bushels. The solid black areas roughly outline the districts in which most of the export rye was produced. The shaded areas outline those districts whose combined surplus was sufficient to cover the local domestic deficits within the boundary of the old Kingdom of Hungary. The deficit districts are roughly outlined by the unshaded areas. The surplus producing area of residual Hungary is situated in the northwestern part of the country.

April. With such a small price difference, it is natural that consumers should prefer wheat flour for bread and that the domestic consumption of rye should be less than normal.

TABLE 24.—*Rye: Average price in Budapest, by months, January, 1922–December, 1925, January, 1927–July, 1928*

Month	1922		1922–23		1923–24		1924–25		1925–26		1926–27		1927–28	
	Crowns per quintal	Cents per bushel	Crowns per quintal	Cents per bushel	Crowns per quintal	Cents per bushel	Crowns per quintal	Cents per bushel	Crowns per quintal	Cents per bushel	Pengös per quintal	Cents per bushel	Pengös per quintal	Cents per bushel
August			5,077	77	50,610	129	344,333	114	282,283	100	(1)		27.52	122
September			6,540	66	62,120	158	358,700	118	266,510	95	(1)		28.42	126
October			7,370	75	63,176	160	428,462	141	247,638	88	(1)		28.43	126
November			6,843	70	69,938	178	413,229	136	227,250	81	(1)		28.23	125
December			7,211	73	81,457	207	419,479	139	255,208	91	(1)		29.15	129
January	1,520	58	8,136	83	109,375	108	478,700	164	(1)		[2] 26.50	118	29.06	129
February	1,715	65	8,165	83	184,427	155	491,685	175	(1)		(1)		29.35	130
March	1,971	65	10,279	78	266,875	102	445,650	158	(1)		(1)		31.26	139
April	2,370	78	14,831	75	277,554	99	457,717	163	(1)		[2] 29.00	129	32.11	142
May	2,925	97	17,057	87	312,115	103	417,200	148	(1)		(1)		30.85	137
June	3,256	91	24,100	61	267,272	81	411,957	147	(1)		29.26	130	30.20	134
July	4,803	98	35,779	91	316,538	96	358,981	128	(1)		26.42	117	24.73	110

January, 1922, to July, 1928, from Inst. Internatl. Statis. Bul. Mens. Off. Permanent.
See Table 54 for average values of the crown and pengö.

[1] Not available.

[2] Prices at end of month (3, p. 72).

Monthly prices in Hungary are not available from January, 1926, through December, 1926, but the yearly average quotation for rye in 1926 in Budapest was 20.09 pengös per 100 kilograms ($0.90 per bushel), as compared with 28.01 schillings per 100 kilograms ($1 per bushel) in Vienna and 158.6 crowns ($1.19 per bushel) in Prague. In 1927 the annual average was 27.85 pengös per 100 kilograms ($1.24 per bushel) in Budapest, as compared with 37.86 schillings per 100 kilograms ($1.35 per bushel) in Vienna, whereas the Prague quotation reached 223.66 crowns per 100 kilograms ($1.68 per bushel).

By March, 1928, Prague was offering 236.43 crowns per 100 kilograms ($1.78 per bushel) and Vienna 42 schillings ($1.50 per bushel). With the Budapest price at 31.26 pengös per 100 kilograms ($1.39 per bushel), rye moved up the Danube, although the shortage at home was acute. This relative price relationship among these three countries as regards rye fluctuated somewhat during April, May, and June, but in general there was a strong demand in Czechoslovakia and Austria for Hungarian rye. At the same time, the demand for wheat by these countries was relatively less.

The peculiar geographic position of the rye-surplus districts and the organization of the export trade subjects the rye of Hungary to unusual and wide fluctuations as regards the relationships of production to export and domestic disappearance. Price relationships favoring export will always draw rye out of the country regardless of the usual domestic demand.

TABLE 25.—*Rye:*[1] *Acreage and production in Hungary, 1877–1928*

Year	Hungary (proper)			Croatia and Slavonia			Total Hungary		
	Acreage	Production	Yield per acre	Acreage	Production	Yield per acre	Acreage	Production	Yield per acre
	1,000 acres	*1,000 bushels*	*Bushels*	*1,000 acres*	*1,000 bushels*	*Bushels*	*1,000 acres*	*1,000 bushels*	*Bushels*
Pre-war years:									
1877	3,101	[2] 38,051	12.27				3,101	38,051	12.27
1878	3,267	[2] 52,049	15.93				3,267	52,049	15.93
1879	2,968	[2] 24,214	8.16				2,968	24,214	8.16
1880	2,693	[2] 34,592	12.85				2,693	34,592	12.85
1881	2,698	[2] 40,321	14.95				2,698	40,324	14.95
1882	2,698	[2] 50,653	18.77				2,698	50,653	18.77
1883	2,723	[2] 40,219	14.77				2,723	40,219	14.77
1884	2,738	[2] 43,102	15.74				2,738	43,102	15.74
1885	2,805	41,344	14.74	289	3,079	10.65	3,094	44,423	14.36
1886	2,790	37,100	13.30	287	3,303	11.51	3,077	40,403	13.13
1887	2,782	50,851	18.28	279	2,972	10.65	3,061	53,823	17.58
1888	2,740	41,820	15.26	277	2,992	10.80	3,017	44,812	14.85
1889	2,686	36,466	13.58	277	2,571	9.28	2,963	39,037	13.17
1890	2,691	49,749	18.49	277	2,988	10.79	2,968	52,737	17.77
1891	2,562	37,025	14.45	259	2,874	11.10	2,821	39,899	14.14
1892	2,740	46,092	16.82	257	2,433	9.47	2,997	48,525	16.19
1893	3,049	55,489	18.20	259	2,976	11.49	3,308	58,465	17.67
1894	2,758	54,934	19.92	264	3,338	12.64	3,022	58,272	19.28
1895	2,580	44,887	17.40	242	1,882	7.78	2,822	46,769	16.57
1896	2,585	48,131	18.62	242	2,945	12.17	2,827	51,076	18.07
1897	2,473	33,955	13.73	235	2,264	9.63	2,708	36,219	13.37
1898	2,511	42,797	17.04	225	3,496	15.54	2,736	46,293	16.92
1899	2,599	47,202	18.16	217	2,669	12.30	2,816	49,871	17.71
1900	2,548	40,206	15.78	205	2,287	11.16	2,753	42,493	15.44
1901	2,590	40,884	15.79	205	2,775	13.54	2,795	43,659	15.62
1902	2,597	49,458	19.04	222	3,051	13.74	2,819	52,509	18.63
1903	2,602	47,356	18.20	215	3,386	15.75	2,817	50,712	18.01
1904	2,565	43,879	17.11	213	2,039	9.57	2,778	45,918	16.53
1905	2,602	50,544	19.43	203	2,535	12.49	2,805	53,079	18.92
1906	2,629	51,962	19.76	188	1,917	10.20	2,817	53,879	19.13
1907	2,461	39,445	16.03	171	2,136	12.49	2,632	41,581	15.80
1908	2,575	45,185	17.55	175	2,520	14.40	2,750	47,705	17.35

[1] Includes spelt through 1906; converted to bushels, using rye equivalent.
[2] Winchester bushels converted from hectoliters.

TABLE 25.—*Rye: Acreage and production in Hungary, 1877–1928*—Continued

Year	Hungary (proper)			Croatia and Slavonia			Total Hungary		
	Acreage	Production	Yield per acre	Acreage	Production	Yield per acre	Acreage	Production	Yield per acre
	1,000 acres	*1,000 bushels*	*Bushels*	*1,000 acres*	*1,000 bushels*	*Bushels*	*1,000 acres*	*1,000 bushels*	*Bushels*
Pre-war years:									
1909	2,486	44,856	18.04	172	2,390	13.90	2,658	47,246	17.78
1910	2,634	49,686	18.86	176	2,106	11.97	2,810	51,792	18.43
1911	2,557	47,785	18.69	176	2,543	14.45	2,733	50,328	18.41
1912	2,654	51,442	19.38	164	1,752	10.68	2,818	53,194	18.88
1913	2,558	50,166	19.61	166	2,531	15.25	2,724	52,697	19.35
War years:									
1914	2,639	42,411	16.07	220	3,027	13.76	2,859	45,438	15.89
1915	2,570	45,682	17.78	205	2,094	10.21	2,775	47,776	17.22
1916	2,536	37,408	14.75	170	1,374	8.08	2,706	38,782	14.33
1917	2,524	39,936	15.82	[3]	[3]	--------	2,524	39,936	15.82
1918	2,453	32,439	13.22	[3]	[3]	--------	2,453	32,439	13.22
Post-war years:									
1919	[4]	[4]	--------	[3]	[3]	--------	[4]	[4]	[4]
1920	1,475	20,248	13.73	[3]	[3]	--------	1,475	20,248	13.73
1921	1,341	23,177	17.28	[3]	[3]	--------	1,341	23,177	17.28
1922	1,663	25,147	15.12	[3]	[3]	--------	1,663	25,147	15.12
1923	1,620	31,274	19.30	[3]	[3]	--------	1,620	31,274	19.30
1924	1,638	22,103	13.49	[3]	[3]	--------	1,638	22,103	13.49
1925	1,699	32,526	19.14	[3]	[3]	--------	1,699	32,526	19.14
1926	1,729	31,416	18.17	[3]	[3]	--------	1,729	31,416	18.17
1927	1,657	22,365	13.50	[3]	[3]	--------	1,657	22,365	13.50
1928	1,641	32,528	19.82	[3]	[3]	--------	1,641	32,528	19.82

1877–1896 from Das Getreide im Weltverkehr, Austria 1900: 50–53.
1897–1904 from Das Getreide im Weltverkehr, Austria 1905: 20–21.
1905–1906 from Das Getreide im Weltverkehr, Austria 1909: 16–17.
1907–1908 from Magyar Statisztikai Évkön. 1910: 100–101.
1909–1912 from Magyar Statisztikai Évkön. 1913: 87–88.
1913–1915 from Magyar Statisztikai Évkön. 1915: 86–87.
1916–1918 from Ann. Statis. Hongrois 1916, 1917, 1918: 40–44, 47–52.
1920 from Ann. Statis. Hongrois 1919–1922: 56, 60.
1921–1928 from official records of U. S. Department Agriculture, Bureau of Agricultural Economics.

[3] Ceded to Yugoslavia. [4] Not available.

BREAD CEREALS

The exports of wheat and rye flour were not stated separately in Hungarian statistics until the season 1906–07 because the use of these two flours was closely related and in a sense interchangeable in the deficit districts of the former Austro-Hungarian Monarchy, to which wheat and rye products were shipped from the old Kingdom of Hungary. In the old Kingdom of Hungary there does not appear to have been a year-to-year inverse relationship between the disappearance of wheat and rye. In some countries, a decrease in wheat disappearance is often associated with an increase in that of rye, but, before the World War, only once (in 1912–13) was a decrease in wheat disappearance in the old Kingdom of Hungary associated with an increased disappearance of rye.

During the eight crop years 1920–21 to 1927–28, there was only one season during which an inverse relationship between the use of wheat and rye was indicated. In 1927–28, a per capita decrease of 0.4 bushel of rye was associated with an increased per capita disappearance of 0.17 bushel of wheat. In other years, the wheat and rye disappearance fluctuated together.

Before the World War it was customary for the officials of the Austro-Hungarian Monarchy to consider the two bread cereals together on a flour basis. An analysis of the postwar bread-cereal situation on a flour basis is therefore not out of place.

THE RELATION OF PRODUCTION AND DISAPPEARANCE TO THE EXPORT OF BREAD CEREAL

Before the World War, the disappearance of bread cereals in Hungary averaged 10,663,000 bushels of rye [26] and 40,462,000 bushels of wheat. The pre-war milling coefficients in Austria-Hungary were 72 per cent for rye and 76.2 per cent for wheat; this indicates a pre-war disappearance of 429,932,000 pounds of rye flour and 1,849,923,000 pounds of wheat flour, or a total of 2,279,-855,000 pounds of flour. The average per capita disappearance of wheat and rye flour during 1909–10 to 1913–14 averaged 300 pounds.

During the four seasons 1922–23, 1923–24, 1925–26, and 1926–27, the disappearance of bread cereals in Hungary averaged 18,637,000 bushels of rye [26] and 41,330,000 bushels of wheat. If the pre-war milling coefficients are employed, these quantities are equivalent to 751,444,000 pounds of rye flour and 1,889,608,000 pounds of wheat flour, or a total of 2,641,052,000 pounds of flour. The average per capita disappearance of wheat and rye flour during these four years was 318 pounds as compared with 300 pounds before the World War.

During the interval between the two periods, population had increased from 7,606,917, before the World War to an average of 8,293,711, during the postwar period. A part of the increased total disappearance of 361,197,000 pounds of flour is associated with increased population. A higher standard of living has also been established as evidenced by an increase of 18 pounds in per capita disappearance.

Before the World War per capita net production of bread cereals in residual Hungary was equivalent to 507 pounds of wheat and rye flour. Production had decreased to an average equivalent to 435 pounds of flour per capita during the four years 1922–23, 1923–24, 1925–26, and 1926–27. Disappearance had increased from 300 pounds to 318 and, consequently, average exports were cut nearly in half. A comparison of the pre-war average with that of the four post-war years shows a drop in net exports of wheat and rye from the equivalent of 207 pounds of flour per capita to 117 pounds. (Table 26.)

Table 26.—*Wheat and rye:* [a] *Per capita net production, export and disappearance, average, old Kingdom of Hungary, 1909–10 to 1913–14, and annual Hungary present boundary, 1922–23, 1923–24, 1925–26, and 1926–27*

Crop year	Per capita net		
	Production *P*	Exports *E*	Disappearance *D*
	Pounds	*Pounds*	*Pounds*
Old Kingdom of Hungary: Average 1909–10 to 1913–14	507	207	300
Present boundary:			
1922–23	355	41	314
1923–24	450	120	330
1925–26	465	139	326
1926–27	470	166	304
Average	435	117	318

[a] Wheat and wheat flour and rye and rye flour expressed in terms of flour.

[26] Includes maslin, which is a mixture of wheat and rye sown together. This mixture is harvested and milled in local gristmills for consumption by the farmer's own family.

The per capita net disappearance of wheat, rye, and maslin flour has remained remarkably uniform during these four years, ranging from 12 pounds above to 14 pounds below the mean of 318 pounds per capita. On the other hand, as production has ranged up or down exports have tended on the average to range in like direction. (Table 27.)

TABLE 27.—*Wheat and rye:*[1] *Per capita net production and per capita net export in Hungary, present boundary, 1922–23, 1923–24, 1925–26, and 1926–27*

Crop year	Per capita net production P	Per capita net exports E	EP	P^2	E^2
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*
1922-23	355	41	14,555	126,025	1,681
1923-24	450	120	54,000	202,500	14,400
1925-26	465	139	64,635	216,225	19,321
1926-27	470	166	78,020	220,900	27,556
Total (Σ)	1,740	466	211,210	765,650	62,958

[1] Wheat and wheat flour and rye and rye flour expressed in terms of flour.

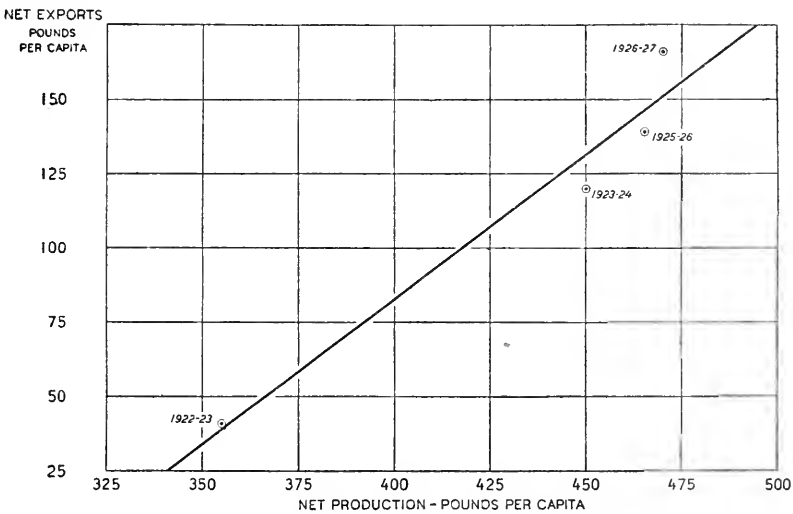

FIGURE 7.—RELATION BETWEEN PER CAPITA NET PRODUCTION OF WHEAT AND RYE, EXPRESSED IN TERMS OF FLOUR, AND PER CAPITA NET EXPORTS OF WHEAT AND RYE, EXPRESSED IN TERMS OF FLOUR IN RESIDUAL HUNGARY, 1922-23, 1923-24, 1925-26, AND 1926-27

Since wheat and rye are interchangeable in making bread in residual Hungary, a description of these bread cereals would not be complete without considering the relationships between the per capita net production of wheat plus rye and the combined per capita net exports of these two cereals.

If the totals in the columns of Table 27 are substituted in the normal equations given on page 37, it is seen that $E' = 0.9715\,P - 306$. The values for E' coincident with the per capita net production of each of the crop years are given in column 4 of Table 28. These values for E' all fall in the straight line of average relationship plotted in Figure 7.

TABLE 28.—*Wheat and rye:* [1] *Estimated equivalent of the per capita net export of bread cereals under average conditions contrasted with that of observed per capita net export in Hungary, present boundary, 1922–23, 1923–24, 1925–26, and 1926–27*

Crop year	Per capita net production	Production multiplied by ratio of variation	Estimated per capita net export under average conditions	Observed per capita net export	Difference between estimated and observed	$(E-E')^2$
	P	bP	$bP+a$[2] $=E'$	E	$E-E'$	
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
1922–23	355	345	39	41	+2	4
1923–24	450	437	131	120	−11	121
1925–26	465	452	146	139	−7	49
1926–27	470	457	151	166	+15	225
Total (Σ)						399

[1] Wheat and wheat flour and rye and rye flour expressed in terms of flour.
[2] a is an algebraically negative quantity in this case.

The dispersion of the observed values of (E) above and below the line of average relationship is relatively less (fig. 7) than in the case of rye. (Fig. 6.) The value of the standard error of estimate is therefore proportionately smaller.

Substituting in the equation $S=\pm\sqrt{\frac{\Sigma(E-E')^2}{n}}$ gives $S=\pm 10$.

The net production of wheat in 1927 was estimated at 65,195,000 bushels, equivalent to 2,980,715,000 pounds of flour. Net production of rye (including maslin) was 17,376,000 bushels, equivalent to 700,600,000 pounds of flour. The total flour equivalent of the bread cereal production in 1927 was thus 3,681,315,000 pounds or 432 pounds per capita.

The per capita net export under average conditions that might be expected to follow a production of 432 pounds is estimated by substituting in the equation

$$E'=0.9715P-306$$

$$E'=114$$

There was the probability that in 68 out of 100 chances the flour equivalent of the exports of wheat and rye would approximate 114 pounds within a range of ± 10 pounds per capita. In 95 cases out of 100, the range should not be greater than ±20 pounds per capita.

Preliminary reports for the year August 1, 1927, to July 31, 1928, placed the net exports of wheat from residual Hungary at 12,004,246 bushels of grain and 2,108,172 barrels of flour. Employing 76.2 per cent as the factor to convert grain to flour gives a total wheat export equivalent to 962,036,000 pounds of flour. The net rye export during 1927–28 has been placed at 3,869,070 bushels of grain and 100,281 barrels of flour. If 72 per cent is employed as the factor to convert grain to flour, the total rye export was equivalent to 175,656,000 pounds of flour. The total bread cereal export was, thus, equivalent to 1,137,692,000 pounds of flour or 134 pounds per capita or 20 pounds higher than the estimated export of 114 pounds per capita.

The mathematical description of the relations of production to disappearance and exportation outlined above is not a method for accurately forecasting the expectancy in exportation to be associated with the production of any given year. It does, however, accurately describe past performance and furnishes a descriptive basis for forecasting probably future performance under the average conditions of the group of variables employed to obtain that average.

At the beginning of the season of 1927–28, wheat moved with difficulty because of relatively unprofitable quotations in Vienna and Prague. Although there was a greater crop in Hungary than during the previous season, exports were light during the first few months following the harvest, and it is probable that grain and flour were accumulated in warehouses. This is exactly the reverse of the rye situation. The shortage of the rye crop was sufficient to warrant an import, if average disappearance were to be maintained, and yet the price pull from Vienna and Prague was great enough to make it profitable to export. Merchants bought and exported rye wherever possible. As the surplus rye in the northwestern districts was shipped out of the country, prices rose to nearly a parity with wheat and rye movement slackened. The unavailability of rye probably tended to release stored wheat and flour, but toward the close of the crop year the exports of rye, as compared with those of the first part of 1927–28, tended to be relatively greater than the exports of wheat.

During the last four months of the crop year Hungary exported the equivalent of 4,561,000 bushels of wheat or 21.2 per cent as much as the total gross exports of 1927–28. At the same time 1,264,000 bushels of rye, or 32.7 per cent of the year's total, was shipped up the Danube. The proximity of surplus-producing regions to demand centers and the relative price pull of the domestic and foreign markets are highly important factors in determining the manner in which the production of an exporting country is utilized. Abnormal conditions in price relationships create widely fluctuating results. In years of abnormal production, under stress of price fluctuations, the substitution of one cereal for another may create a wide departure from the average relationships that might have been expected under normal conditions.

BARLEY

Before the World War residual Hungary seeded 1,322,000 acres of barley annually. By 1927 barley acreage had decreased more than 300,000 acres. Yields per acre had also fallen off to such an extent that the 1923–1927 average was 2.1 bushels per acre below that of 1909–1913. Net production, during the 5-year period ended 1927, was thus reduced to an average of 20,367,200 bushels, as compared with 28,535,000 bushels before the World War. (Table 29.)

TABLE 29.—*Barley: Statistical balances of present Hungary, average 1909–1913, and annual 1921–22 to 1928–29*

Crop year	Acreage	Seed [1]	Production: Gross	Production: Net [2]	Disappearance: Total	Disappearance: Per capita [3]	Exportable surplus
	1,000 acres	*1,000 bushels*	*1,000 bushels*	*1,000 bushels*	*1,000 bushels*	*Bushels*	*1,000 bushels*
Pre-war average: [4]							
1909–1913	1,322	3,834	32,369	28,535	[5] 19,926	2.62	8,609
Post-war years: [6]							
1921–22	1,184	3,434	21,408	18,088	17,908	2.22	[7] 180
1922–23	1,145	3,320	22,169	18,872	18,871	2.32	[7] 1
1923–24	1,137	3,297	27,271	24,348	24,013	2.92	[7] 335
1924–25	1,008	2,923	14,712	11,757	11,525	1.39	[7] 232
1925–26	1,019	2,955	25,430	22,385	20,115	2.40	[7] 2,270
1926–27	1,050	3,045	25,509	22,603	20,261	2.40	[7] 2,342
1927–28	1,002	2,906	23,684	20,743	18,559	2.18	[7] 2,184
1928–29	1,014	2,941	27,871	24,930			

[1] 2.9 bushels per acre (*10*, *p. 22*).
[2] Production for stated year, minus seed for the following year except for average 1909–1913 and annual 1928–29.
[3] See Table 8 for populations.
[4] Acreage and production calculated from Magyar Statisztikai Évkön. 1909–1913.
[5] From *10*, *p. 22*.—Barley fed to swine plus estimate for that used industrially.
[6] Acreage and production 1921–1928 from official records of U. S. Department of Agriculture, Bureau of Agricultural Economics.
[7] Net exports for years beginning August 1, from Internatl. Yearbook Agr. Statis. 1924–25, and 1927–28.

As indicated in Table 1, the large estates seeded 13.2 per cent of their cereal acreage to barley in 1926, whereas the small farmers seeded about 10.3 per cent. The transfer of 1,246,000 acres of plowlands from the management of the estates into the hands of small peasant farmers accounts for the general reduction in barley acreage throughout Hungary. It is probable that the new level of barley acreage fluctuating about the 1923–1927 average of 1,043,000 acres indicates the future level of Hungary's barley production.

The malt industry of Hungary depends entirely upon the export possibilities for its prosperity. The domestic breweries produce more malt than they need for their own consumption; the factories exclusively engaged in producing malt are dependent upon foreign countries for their market. The sale of malt abroad, however, is accompanied by many difficulties, among which are the customs barriers of surrounding countries and the unfavorable position of Hungarian malt in respect to freight tariffs, as compared with its great competitor, the malt of Czechoslovakia. In spite of these difficulties, the export of malt increased from 7,083 short tons in 1926 to 7,841 short tons in 1927. The greatest quantity, 2,358 short tons, was exported to Austria. Switzerland took 1,923 short tons; Yugoslavia, 1,129; Holland, 1,100; Italy, 892; Germany, 372; and Portugal, 67 short tons. The import amounted to 4 short tons. (Commerce and Industry of Hungary in the year 1927, 1928, p. 107.)

If the poor crop season of 1924–25 is excluded, the per capita net disappearance of barley since the World War has averaged 2.41 bushels, or nearly the same as during 1909–1913, 2.62 bushels. As a result, the surplus available for export was reduced to negligible proportions until 1925–26. Before the World War, the territories within the present boundaries of Hungary produced a surplus of approximately 8,609,000 bushels, whereas actual average exports during 1921–1924 amounted to only 187,000 bushels. However, beginning with the season 1925–26, exports rose to more than 2,200,000 bushels.

TABLE 30.—*Barley: Acreage and production in Hungary, 1877–1928*

Year	Hungary (proper)			Croatia and Slavonia			Total Hungary		
	Acreage	Production	Yield per acre	Acreage	Production	Yield per acre	Acreage	Production	Yield per acre
	1,000 acres	*1,000 bushels*	*Bushels*	*1,000 acres*	*1,000 bushels*	*Bushels*	*1,000 acres*	*1,000 bushels*	*Bushels*
Pre-war years:									
1877	2,301	[1] 34,458	14.98	-------	-------	-------	2,301	34,458	14.98
1878	2,471	[1] 47,415	19.19	-------	-------	-------	2,471	47,415	19.19
1879	2,429	[1] 26,200	10.79	-------	-------	-------	2,429	26,200	10.79
1880	2,417	[1] 50,917	21.07	-------	-------	-------	2,417	50,917	21.07
1881	2,251	[1] 39,912	17.73	-------	-------	-------	2,251	39,912	17.73
1882	2,399	[1] 57,566	24.00	-------	-------	-------	2,399	57,566	24.00
1883	2,402	[1] 39,299	16.36	-------	-------	-------	2,402	39,299	16.36
1884	2,459	[1] 46,816	19.04	-------	-------	-------	2,459	46,816	19.04
1885	2,585	56,690	21.93	173	2,544	14.71	2,758	59,234	21.48
1886	2,580	39,517	15.32	170	2,453	14.43	2,750	41,970	15.26
1887	2,481	58,151	23.44	168	2,191	13.04	2,649	60,342	22.78
1888	2,424	47,054	19.41	166	2,131	12.84	2,590	49,185	18.99
1889	2,488	36,008	14.47	158	1,782	11.28	2,646	37,790	14.28
1890	2,488	55,198	22.19	166	2,370	14.28	2,654	57,568	21.69
1891	2,577	57,159	22.18	161	2,044	12.70	2,738	59,203	21.62
1892	2,577	54,146	21.01	168	2,182	12.99	2,745	56,328	20.52
1893	2,585	64,756	25.05	166	2,420	14.58	2,751	67,176	24.42
1894	2,609	60,227	23.08	170	2,838	16.69	2,779	63,065	22.69
1895	2,496	54,495	21.83	163	2,356	14.45	2,659	56,851	21.38
1896	2,496	61,012	24.44	170	2,990	17.59	2,666	64,002	24.01
1897	2,338	42,025	17.97	156	2,081	13.34	2,494	44,106	17.68
1898	2,409	57,333	23.80	175	3,541	20.23	2,584	60,874	23.56
1899	2,511	61,586	24.53	170	2,733	16.08	2,681	64,319	23.99
1900	2,486	53,875	21.67	183	2,903	15.86	2,669	56,778	21.27
1901	2,503	50,072	20.00	178	3,050	17.13	2,681	53,122	19.81
1902	2,523	62,349	24.71	173	3,261	18.85	2,696	65,610	24.34
1903	2,567	64,576	25.16	178	3,840	21.57	2,745	68,416	24.92
1904	2,520	49,916	19.81	173	2,283	13.20	2,693	52,199	19.38
1905	2,550	62,454	24.49	170	2,866	16.86	2,720	65,320	24.01
1906	2,602	69,748	26.81	166	2,756	16.60	2,768	72,504	26.19
1907	2,725	63,077	23.15	161	2,064	12.82	2,886	65,141	22.57
1908	2,647	56,323	21.28	160	2,552	15.95	2,807	58,875	20.97
1909	2,858	71,870	25.15	157	2,347	14.95	3,015	74,217	24.62
1910	2,716	53,627	19.74	158	2,104	13.32	2,874	55,731	19.39
1911	2,736	73,597	26.90	158	2,641	16.72	2,894	76,238	26.34
1912	2,603	70,143	26.95	156	1,975	12.66	2,759	72,118	26.14
1913	2,887	79,825	27.65	158	3,123	19.77	3,045	82,948	27.24
War years:									
1914	2,705	65,265	24.13	154	2,342	15.21	2,859	67,607	23.65
1915	2,786	58,302	20.93	151	1,690	11.19	2,937	59,992	20.43
1916	2,648	51,891	19.60	148	1,605	10.84	2,796	53,496	19.13
1917	2,506	36,947	14.74	(2)	(2)	-------	2,506	36,947	14.74
1918	2,321	40,365	17.39	(2)	(2)	-------	2,321	40,365	17.39
Post-war years:									
1919	(3)	(3)	(3)	(2)	(2)	-------	(3)	(3)	(3)
1920	1,266	21,672	17.12	(2)	(2)	-------	1,266	21,672	17.12
1921	1,184	21,408	18.08	(2)	(2)	-------	1,184	21,508	18.08
1922	1,145	22,169	19.36	(2)	(2)	-------	1,145	22,169	19.36
1923	1,137	27,271	23.99	(2)	(2)	-------	1,137	27,271	23.99
1924	1,008	14,712	14.60	(2)	(2)	-------	1,008	14,712	14.60
1925	1,019	25,430	24.96	(2)	(2)	-------	1,019	25,430	24.96
1926	1,050	25,509	24.29	(2)	(2)	-------	1,050	25,509	24.29
1927	1,002	23,684	23.64	(2)	(2)	-------	1,002	23,684	23.64
1928	1,014	27,871	27.49	(2)	(2)	-------	1,014	27,871	27.49

1877-1896 from Das Getreide im Weltverkehr, Austria 1900: 50–53.
1897-1904 from Das Getreide im Weltverkehr, Austria 1905: 20–21.
1905-1906 from Das Getreide im Weltverkehr, Austria 1909: 16–17.
1907-1908 from Magyar Statisztikai Évkön. 1910: 100–101.
1909-1912 from Magyar Statisztikai Évkön. 1913: 87–88.
1913-1915 from Magyar Statisztikai Évkön. 1913: 86–87.
1916-1918 from Ann. Statis. Hongrois 1916, 1917, 1918: 40–44, 47–52.
1920 from Ann. Statis. Hongrois 1919-1922: 56, 60.
1921-1928 from official records of U. S. Department of Agriculture, Bureau of Agricultural Economics.

[1] Winchester bushels converted from hectoliters.
[2] Ceded to Yugoslavia.
[3] Not available.

The barley crop of 1927 was very good as regards quality although far below the pre-war average production and smaller than the previous year. The breweries, both domestic and foreign, took an interest in Hungarian barley soon after it began to come on the market. Thanks to the superior quality of the 1927 crop, new markets were obtained in Great Britain (137,000 bushels), and in Poland (10,000 bushels brewer's barley, and 4,000 bushels fodder barley). Switzerland, which is very fastidious with respect to the quality of its imported brewer's barley, took 113,000 bushels. The bulk of barley exports went to Austria—936,000 bushels of brewer's barley and 377,000 bushels of fodder barley. The quantities taken by other customer countries were as follows: Germany, 420,000 bushels; Yugoslavia, 281,000 bushels. A total of 2,278,000 bushels was exported during the calendar year 1927. This is about one-fourth of the pre-war performance, and it is probable that this low volume of barley exports will not be greatly exceeded in future years. In the first place, the greater peasant influence in Hungarian agriculture that has followed the land reform has tended toward lower yields per acre. There will probably be a greater demand for barley as a feeding stuff for livestock within the country itself.

OATS

Before the World War, residual Hungary seeded 849,000 acres of oats annually. In 1927, only 643,000 acres were planted. The average yield per acre during the 5-year period ended in 1927 was 32.6 bushels, as compared with the 1909–1913 average of 33.5 bushels. This indicates a general trend, since the war toward slightly lower yields. Average net production has decreased (Table 31) from 24,771,000 bushels during 1909–1913 to 20,248,000 bushels for the 5-year period ended 1927.

TABLE 31.—*Oats: Statistical balances of present Hungary, average 1909–1913, and annual 1921–22 to 1928–29*

Crop year	Acreage	Seed [1]	Production		Disappearance		Exportable surplus
			Gross	Net	Statistical	Per horse [2]	
	1,000 acres	*1,000 bushels*	*1,000 bushels*	*1,000 bushels*	*1,000 bushels*	*Bushels*	*1,000 bushels*
Pre-war averages:[3]							
1909–1913	849	3,693	28,464	21,771	22,189	[4] 25.19	2,582
Post-war years:[5]							
1921–22	885	3,850	21,964	[6] 18,436	17,870	25.49	[7] 566
1922–23	811	3,528	22,553	19,034	17,479	21.38	[7] 1,555
1923–24	809	3,519	27,458	24,378	20,952	25.71	[7] 3,426
1924–25	708	3,080	15,713	12,594	12,426	14.62	[7] 168
1925–26	717	3,119	25,532	22,578	18,702	21.35	[7] 3,876
1926–27	679	2,951	24,802	22,005	19,637	22.19	[7] 2,368
1927–28	643	2,797	22,513	19,684	18,548	20.54	[7] 1,136
1928–29	650	2,829	23,725	20,896			

[1] 4.35 bushels per acre (*10, p. 25*).
[2] See Table 50 for number of horses.
[3] Acreage and production calculated from Magyar Statisztikai Évkön. 1909–1913.
[4] Disappearance per horse as indicated (*10, p. 25*).
[5] Acreage and production 1921–1927 from official records of U. S. Department of Agriculture, Bureau of Agricultural Economics.
[6] Seed for following year subtracted from production for stated year, except average 1909–13, annual 1928–29.
[7] Net exports for years beginning Aug. 1, from Internatl. Yearbook Agr. Statis. 1924–25 and 1927–28.

The peasants seeded only 5.4 per cent of their cereal land to oats, as compared with 10.5 per cent seeded on the large estates during 1926. (Table 1.) The land reform probably has created a permanently depressing influence upon the areas planted to oats. The increased use of motor cars has conspicuously decreased the use of horses in cities. The army has been reduced and is employing motor vehicles in place of horses to a considerable extent. Demand for oats has fallen off, and as a consequence acreage has steadily decreased to a proportion more in keeping with domestic requirements.

Disappearance of oats in recent years has been somewhat less than before the World War. If the poor crop year 1924–25 is excluded, the disappearance of oats between 1922–23 and 1926–27 has averaged 19,192,000 bushels, as compared with 22,189,000 bushels during 1909–1913. During the seasons 1923–24 and 1925–26, net exports of oats were considerably higher than the estimated surplus produced before the World War. During the calendar year 1926, Austria absorbed 77 per cent of the oats exported from Hungary. Czechoslovakia took 13 per cent and Italy 9 per cent. The remaining 1 per cent was divided among Yugoslavia, Switzerland, and Rumania.

The peasants of Hungary do not feed oats to livestock to the extent that this cereal is utilized in central and northwestern Europe. More corn is employed on the small land holdings; therefore, following the land reform, the area seeded to oats in Hungary will probably tend to remain below what was normal before the World War.

The quality of the 1927 crop was excellent; but net production was 2,321,000 bushels below that of 1926. There was thus a tendency to increase domestic prices, which was enhanced by the improvement in the building trade both in Budapest and in the Comitats and by an expansion in road building. Net exports during 1927–28 declined 1,232,000 bushels below those of the season 1926–27. The decline in exports was also affected by favorable harvests in the neighboring States to the west and north. During the greater part of the year, oats were cheaper in Vienna than in Budapest. During the first half of the calendar year 1927 Hungary took a considerable part in supplying the oats required by the Italian Army; but later prices in Hungary rendered this trade unprofitable.

During the calendar year 1927 Hungary exported altogether 1,794,000 bushels of oats. This was apportioned among the various countries as follows: Austria, 1,324,000 bushels; Italy, 249,000 bushels; Czechoslovakia, 198,000 bushels; other countries, 23,000 bushels.

Domestic utilization of oats in Hungary will probably tend to remain below the pre-war average; the result will probably be that net exports, which will fluctuate with seasonal fluctuations in production, will tend to average about the same as before the World War.

TABLE 32.—*Oats: Acreage and production in Hungary, 1877–1928*

Year	Hungary (proper)			Croatia and Slavonia			Total Hungary		
	Acreage	Production	Yield per acre	Acreage	Production	Yield per acre	Acreage	Production	Yield per acre
	1,000 acres	*1,000 bushels*	*Bushels*	*1,000 acres*	*1,000 bushels*	*Bushels*	*1,000 acres*	*1,000 bushels*	*Bushels*
Pre-war years:									
1877	2, 686	[1] 40, 114	14. 93				2, 686	40, 114	14. 93
1878	2, 854	[1] 60, 168	21. 08				2, 854	60, 168	21. 08
1879	2, 691	[1] 38, 252	14. 21				2, 691	38, 252	14. 21
1880	2, 515	[1] 61, 660	24. 52				2, 515	61, 660	24. 52
1881	2, 362	[1] 47, 810	20. 24				2, 362	47, 810	20. 24
1882	2, 469	[1] 67, 500	27. 34				2, 469	67, 500	27. 34
1883	2, 454	[1] 51, 161	20. 85				2, 454	51, 161	20. 85
1884	2, 459	[1] 57, 089	23. 22				2, 459	57, 089	23. 22
1885	2, 565	57, 774	22. 52	277	5, 305	19. 15	2, 842	63, 079	22. 20
1886	2, 602	58, 346	22. 42	274	5, 312	19. 39	2, 876	63, 658	22. 13
1887	2, 585	65, 249	25. 24	274	4, 650	16. 97	2, 859	69, 899	24. 45
1888	2, 582	59, 965	23. 22	264	4, 092	15. 50	2, 846	64, 057	22. 51
1889	2, 515	46, 297	18. 41	242	2, 666	11. 02	2, 757	48, 963	17. 76
1890	2, 454	56, 527	23. 03	240	3, 899	16. 25	2, 694	60, 426	22. 43
1891	2, 488	68, 859	27. 68	235	4, 051	17. 24	2, 723	72, 910	26. 78
1892	2, 481	66, 228	26. 69	235	3, 810	16. 21	2, 716	70, 038	25. 79
1893	2, 397	72, 704	30. 33	230	3, 879	16. 87	2, 627	76, 583	29. 15
1894	2, 436	74, 936	30. 76	230	5, 353	23. 27	2, 666	80, 289	30. 12
1895	2, 377	72, 400	30. 46	215	4, 478	20. 83	2, 592	76, 878	29. 66
1896	2, 318	74, 688	32. 22	227	5, 346	23. 55	2, 545	80, 034	31. 45
1897	2, 216	55, 060	24. 85	235	4, 402	18. 73	2, 451	59, 462	24. 26
1898	2, 340	78, 704	33. 63	217	7, 020	28. 42	2, 587	85, 724	33. 14
1899	2, 382	81, 219	34. 10	245	6, 318	25. 79	2, 627	87, 537	33. 32
1900	2, 424	70, 637	29. 14	247	5, 567	22. 54	2, 671	76, 204	28. 53
1901	2, 427	68, 081	28. 05	247	5, 815	23. 54	2, 674	73, 896	27. 64
1902	2, 434	82, 803	34. 02	245	6, 304	25. 73	2, 679	89, 107	33. 26
1903	2, 528	87, 330	34. 55	250	7, 330	29. 32	2, 778	94, 660	34. 07
1904	2, 456	62, 776	25. 56	247	4, 905	19. 86	2, 703	67, 681	25. 04
1905	2, 513	78, 008	31. 04	247	6, 076	24. 60	2, 760	84, 084	30. 47
1906	2, 562	87, 729	34. 21	252	5, 539	21. 98	2, 814	93, 268	33. 14
1907	2, 653	79, 484	29. 96	249	4, 174	16. 76	2, 902	83, 658	28. 83
1908	2, 612	70, 168	26. 86	247	4, 253	17. 22	2, 859	74, 421	26. 03
1909	2, 695	92, 269	34. 24	247	5, 608	22. 70	2, 942	97, 877	33. 27
1910	2, 640	70, 699	26. 78	241	4, 017	16. 67	2, 881	74, 716	25. 93
1911	2, 653	89, 658	33. 79	247	5, 553	22. 48	2, 900	95, 211	32. 83
1912	2, 473	76, 768	31. 04	237	3, 534	14. 91	2, 710	80, 302	29. 63
1913	2, 884	99, 806	34. 61	271	6, 566	24. 23	3, 155	106, 372	33. 72
War years:									
1914	2, 603	86, 537	33. 25	255	5, 766	22. 61	2, 858	92, 303	32. 30
1915	2, 631	80, 861	30. 73	267	5, 367	20. 10	2, 898	86, 228	29. 75
1916	2, 652	84, 591	31. 90	281	6, 300	22. 42	2, 933	90, 891	30. 99
1917	2, 586	53, 362	20. 63	(2)	(2)		2, 586	53, 362	20. 63
1918	2, 398	45, 928	19. 15	(2)	(2)		2, 398	45, 928	19. 15
Post-war years:									
1919	(3)	(3)	(3)	(2)	(2)		(3)	(3)	(3)
1920	802	22, 307	27. 81	(2)	(2)		802	22, 307	27. 81
1921	885	21, 964	24. 82	(2)	(2)		885	21, 964	24. 82
1922	811	22, 553	27. 81	(2)	(2)		811	22, 553	27. 81
1923	809	27, 458	33. 94	(2)	(2)		809	27, 458	33. 94
1924	708	15, 713	22. 19	(2)	(2)		708	15, 713	22. 19
1925	717	25, 532	35. 61	(2)	(2)		717	25, 532	35. 61
1926	679	24, 802	36. 53	(2)	(2)		679	24, 802	36. 53
1927	643	22, 513	35. 01	(2)	(2)		643	22, 513	35. 01
1928	650	23, 725	36. 50	(2)	(2)		650	23, 725	36. 50

1877–1896 from Das Getreide im Weltverkehr, Austria 1900: 50–53.
1897–1904 from Das Getreide in Weltverkehr, Austria 1905: 20–21.
1905–1906 from Das Getreide in Weltverkehr, Austria 1909: 16–17.
1907–1908 from Magyar Statisztikai Évkön. 1910: 100–101.
1909–1912 from Magyar Statisztikai Évkön. 1913: 87–88.
1913–1915 from Magyar Statisztikai Évkön. 1915: 86–87.
1916–1918 from Ann. Statis. Hongrois 1916, 1917, 1918: 40–44, 47–52.
1920 from Ann. Statis. Hongrois 1919–1922: 56–60.
1921–1928 from official records of U. S. Department of Agriculture, Bureau of Agricultural Economics.

[1] Winchester bushels converted from hectoliters.
[2] Ceded to Yugoslavia.
[3] Not available.

CORN

From 1921 the area planted to corn steadily increased in Hungary until 1926. The pre-war average approximated 2,192,000 acres, whereas in 1926 the acreage was 2,631,000 acres. It fell off slightly to 2,625,000 acres in 1927. Between 1921 and 1923 climatic conditions were unfavorable, and yields per acre were low. Between 1924 and 1926 conditions were more favorable, and net production was relatively high. There was not enough corn produced in 1921 and 1922 to meet the domestic Hungarian requirements (Table 33), and a small net importation was made during each of the calendar years 1922 and 1923.

TABLE 33.—*Corn: Statistical balances of present Hungary average 1909–1913, and annual 1921–22 to 1928–29*

Crop year	Acreage	Seed [1]	Production		Disappearance		Exportable surplus (+) or deficit (−)
			Gross	Net	Statistical	Per capita [2]	
	1000, acres	*1,000 bushels*	*1,000 bushels*	*1,000 bushels*	*1,000 bushels*	*Bushels*	*1,000 bushels*
Pre-war average: [3]							
1909–1913	2, 192	1, 228	60, 813	59, 585	[4] 58, 389	7. 68	+ 1, 196
Post-war years: [5]							
1921–22	2, 167	1, 214	31, 703	[6] 30, 334	30, 554	3. 79	[7] −220
1922–23	2, 445	1, 369	48, 725	47, 348	47, 426	5. 83	[7] −78
1923–24	2, 459	1, 377	49, 247	47, 870	46, 657	5. 68	[7] +1, 213
1924–25	2, 459	1, 377	74, 122	72, 635	65, 813	7. 95	[7] +6, 822
1925–26	2, 655	1, 487	87, 969	86, 496	80, 929	9. 67	[7] +5, 567
1926–27	2, 631	1, 473	76, 544	75, 074	74, 717	8. 85	[7] +357
1927–28	2, 625	1, 470	68, 347	66, 870	---	---	---
1928–29	2, 637	1, 477	43, 324	41, 874	---	---	---

[1] 0.56 bushel per acre (*10, p. 19*).
[2] For populations see Table 8.
[3] Acreage and production calculated from Magyar Statisztikai Évkön, 1909–1913.
[4] Total corn requirement considered to be equivalent to the average disappearance during 1911–1915 (*10, p. 19*).
[5] Acreage and production 1921–1928 from official records of U. S. Department of Agriculture, Bureau of Agricultural Economics.
[6] Seed for following year subtracted from production for stated year, except for average 1909–1913 and annual 1928–29.
[7] Net imports indicated by (−) and net exports by (+) for calendar years following the crop year from Internatl. Yearbook Agr. Statis. 1925–26 and 1927–28.

Climatical conditions in 1924 brought net production to 13,000,000 bushels above the pre-war normal, all but 6,822,000 bushels of which were absorbed within the country itself. The following year, another bumper crop followed increased acreage and favorable climatical conditions. Only 5,567,000 bushels were exported against 81,000,000 bushels domestic disappearance. It is estimated that about 62,595,000 bushels of corn were fed to hogs and fowls in 1925. Some corn was fed to cattle, horses, and sheep, and some was utilized industrially but, unlike the custom of Rumania and Yugoslavia, almost no corn was employed as human food.

Although, in 1926, the area planted was 2,631,000 acres (only 24,000 acres below the area of the previous year) the net production was 11,422,000 bushels less. The quality of the crop was good; but on account of smaller production, domestic prices rose, and net exports fell off.

Most of the corn exported during the calendar year 1926, about 3,721,000 bushels went to Czechoslovakia. Austria took 1,522,000 bushels. The balance went to other countries, including Germany, Italy, and Switzerland.

The corn crop of 1927 was adversely affected by frosts in May. Rains in September and subsequent warm weather greatly improved the injured crop; but the final net production was 8,204,000 bushels below that of the previous year. Prices rose, and export stagnated. During the first part of the calendar year 1927 some old corn of the previous crop was shipped abroad; but during the second half, corn was imported. The gross exports reached 1,352,000 bushels, which was scarcely a quarter of the exports of the preceding year (5,569,000 bushels). The leading customers were Czechoslovakia, which took 818,000 bushels, and Austria, which took 486,000 bushels.

The depressed state of the Vienna livestock market, as compared with the great numbers of cattle and swine in demand before the World War, has had a profound effect upon the feed-lot industry in the territories now comprising Hungary. In pre-war days thousands of lean animals, as well as large quantities of feeding stuffs, were shipped to the feed lots near Budapest and in the western Comitats where fat stock was prepared for the Vienna market. It is probable that as Vienna recovers its purchasing power the feed-lot industry of Hungary will be revived and that not only will all domestically produced corn be fed at home but further quantities may be imported from Rumania and Yugoslavia.

Late in 1927, the Ministry of Agriculture allowed the duty-free import of 995,000 bushels of corn, principally from Yugoslavia and Rumania, for use in the transit-fattening business. Under these provisions, commercial feeding organizations are allowed to import corn for reexport in the form of pork and lard.

Increased acreage and production of corn in Hungary is probably an after effect of the land reform. It is probable, also, that the disappearance of corn will increase in Hungary since the general trend of peasant agriculture will be to raise more corn and hogs in proportion to the area of plowland than was customary on the large estates where oat production in connection with horse breeding was preferred to corn and swine.

TABLE 34.—*Corn: Acreage and production in Hungary, 1877–1928*

Year	Hungary (proper)			Croatia and Slavonia			Total Hungary		
	Acreage	Production	Yield per acre	Acreage	Production	Yield per acre	Acreage	Production	Yield per acre
	1,000 acres	*1,000 bushels*	*Bushels*	*1,000 acres*	*1,000 bushels*	*Bushels*	*1,000 acres*	*1,000 bushels*	*Bushels*
Pre-war years:									
1877	4,346	[1] 54,200	12.47				4,346	54,200	12.47
1878	4,680	[1] 102,864	21.98				4,680	102,864	21.98
1879	4,633	[1] 65,957	14.24				4,633	65,957	14.24
1880	4,611	[1] 98,769	21.42				4,611	98,769	21.42
1881	4,438	[1] 81,913	18.46				4,438	81,913	18.46
1882	4,680	[1] 107,523	22.98				4,680	107,523	22.98
1883	4,507	[1] 87,231	19.35				4,507	87,231	19.35
1884	4,586	[1] 90,341	19.70				4,586	90,341	19.70
1885	4,633	111,399	24.04	761	11,725	15.41	5,394	123,123	22.83
1886	4,729	86,251	18.24	773	13,653	17.66	5,502	99,904	18.16
1887	4,517	75,271	16.66	773	11,149	14.42	5,290	86,420	16.31
1888	4,608	97,392	21.14	791	13,562	17.15	5,399	110,954	20.55
1889	4,789	104,549	21.83	798	12,944	16.22	5,587	117,493	21.03
1890	4,774	91,412	19.15	815	13,354	16.39	5,589	104,766	18.75
1891	4,972	149,011	29.97	857	16,247	18.96	5,829	165,258	28.35
1892	5,162	118,954	23.04	867	16,231	18.72	6,029	135,185	22.42
1893	5,063	137,134	27.09	877	15,861	18.09	5,940	152,995	25.76
1894	4,996	70,091	14.03	902	12,610	13.98	5,898	82,701	14.02
1895	5,308	146,031	27.51	902	18,735	20.77	6,210	164,766	26.53
1896	5,145	131,248	25.51	904	18,298	20.24	6,049	149,546	24.72
1897	4,912	103,904	21.15	882	14,609	16.56	5,794	118,513	20.15
1898	5,224	127,383	24.38	966	20,463	21.18	6,190	147,846	23.88
1899	5,261	115,982	22.05	909	14,680	16.15	6,170	130,662	21.18

[1] Winchester bushels converted from hectoliters.

TABLE 34.—*Corn: Acreage and production in Hungary, 1877–1928*—Continued

Year	Hungary (proper)			Croatia and Slavonia			Total Hungary		
	Acreage	Production	Yield per acre	Acreage	Production	Yield per acre	Acreage	Production	Yield per acre
	1,000 acres	*1,000 bushels*	*Bushels*	*1,000 acres*	*1,000 bushels*	*Bushels*	*1,000 acres*	*1,000 bushels*	*Bushels*
Pre-war years—Contd.									
1900	5,478	127,654	23.30	917	18,692	20.38	6,395	146,346	22.88
1901	5,434	127,387	23.44	959	20,467	21.34	6,393	147,854	23.13
1902	5,352	104,545	19.53	937	15,255	16.28	6,289	119,800	19.05
1903	5,604	135,748	24.22	974	23,774	24.41	6,578	159,522	24.25
1904	4,853	59,398	12.24	976	11,366	11.65	5,829	70,764	12.14
1905	5,246	94,046	17.93	988	18,385	18.61	6,234	112,431	18.04
1906	5,715	162,924	28.51	1,006	20,471	20.35	6,721	183,395	27.29
1907	6,032	155,617	25.80	988	17,934	18.15	7,020	173,551	24.72
1908	5,831	146,122	25.06	1,004	20,278	20.20	6,835	166,400	24.35
1909	6,061	161,861	26.71	1,001	21,751	21.73	7,062	183,612	26.00
1910	5,998	187,733	31.30	996	25,758	25.86	6,994	213,491	30.52
1911	6,090	137,421	22.57	1,024	24,007	23.44	7,114	161,428	22.69
1912	6,022	176,695	29.34	1,045	24,066	23.03	7,067	200,761	28.41
1913	6,129	182,068	29.71	1,077	28,955	26.88	7,206	211,023	29.28
War years:									
1914	6,015	172,309	28.65	1,057	25,865	24.47	7,002	198,174	28.30
1915	6,084	160,160	26.32	1,043	15,495	14.86	7,127	175,655	24.65
1916	5,829	93,316	16.01	1,082	12,267	11.34	6,911	105,583	15.28
1917	5,778	103,618	17.93	(2)	(2)	--------	5,778	103,618	17.93
1918	5,569	94,378	16.95	(2)	(2)	--------	5,569	94,378	16.95
Post-war years:									
1919	(3)	(3)	(3)	(2)	(2)	--------	(3)	(3)	(3)
1920	2,017	50,163	24.87	(2)	(2)	--------	2,017	50,163	24.87
1921	2,167	31,703	14.63	(2)	(2)	--------	2,167	31,703	14.63
1922	2,445	48,725	19.93	(2)	(2)	--------	2,445	48,725	19.93
1923	2,459	49,247	20.03	(2)	(2)	--------	2,459	49,247	20.03
1924	2,459	74,122	30.14	(2)	(2)	--------	2,459	74,122	30.14
1925	2,655	87,969	33.13	(2)	(2)	--------	2,655	87,969	33.13
1926	2,631	76,544	29.09	(2)	(2)	--------	2,631	76,544	29.09
1927	2,625	68,347	26.04	(2)	(2)	--------	2,625	68,347	26.04
1928	2,637	43,324	16.43	(2)	(2)	--------	2,637	43,324	16.43

1877–1896 from Das Getreide im Weltverkehr, Austria, 1900: 50–53.
1897–1904 from Das Getreide im Weltverkehr, Austria, 1905: 20–21.
1905–6 from Das Getreide im Weltverkehr, Austria, 1909: 16–17.
1907–1908 from Magyar Statisztikai Évkön. 1910: 100–101.
1909–1912 from Magyar Statisztikai Évkön. 1913: 87–88.
1913–1915 from Magyar Statisztikai Évkön. 1915: 85–86.
1916–1918 from Ann. Statis. Hongrois, 1916, 1917, 1918: 40–44, 47–52.
1920 from Ann. Statis. Hongrois, 1920–1922: 56, 60.
1921–1928 from official records of U. S. Department of Agriculture, Bureau of Agricultural Economics.

[2] Ceded to Yugoslavia. [3] Not available.

POTATOES

The territories comprising residual Hungary were just about self-sufficient before the World War, as far as potatoes were concerned. In the spring new potatoes were shipped into Budapest from the southern Comitats now part of Yugoslavia. Later in the season the central Comitats, now constituting Hungary, shipped potatoes to Vienna and Prague. But this trade was unimportant. Only small quantities of potatoes were used industrially, as compared with the quantities in regions like Slovakia, Bohemia, and Galicia, where abundant rainfall makes potatoes a crop of primary agricultural importance. Relatively small quantities of potatoes are fed to swine in Hungary, where pork production, as in the United States, is associated with corn production and is not dependent upon the potato crop, as is the case in Germany and Poland.

The Austrian Government has published estimates of the potato requirements of each of the districts of the old Austro-Hungarian Monarchy (*1, p. 515*), placing the per capita human consumption in the old Kingdom of Hungary at 1.17 quintals or 4.30 bushels per capita. Conditions in the Comitats comprising residual Hungary were about average for the old Kingdom, and this figure may be accepted as representing the pre-war human food requirements of Budapest and the Comitats now comprising the Hungarian State.

The pre-war quantity of potatoes utilized industrially or fed to livestock has been estimated at about 30 per cent of the net production; that is, gross production, less seed, less 10 per cent for decay and for potatoes that have otherwise become unavailable for utilization. The pre-war potato situation in residual Hungary which has been based upon Austrian governmental estimates, may be considered to be approximated by the data in Table 35. The area planted averaged 619,000 acres; which produced 71,118,000 bushels gross, or 48,005,000 bushels net. Of this amount, 32,710,000 bushels were consumed annually as human food, and 14,401,500 bushels were fed to livestock or utilized industrially. The resulting small statistical surplus during 1909–1913 averaged 893,000 bushels per year.

TABLE 35.—*Potatoes: Statistical balances of present Hungary, average 1909–1913, and annual 1921–22 to 1928–29*

Crop year	Acreage	Seed [1]	Production: Gross	Production: Net [2]	Disappearance: Total	Disappearance: Per capita [3]	Exportable surplus (+) or deficit (−)
	1,000 acres	*1,000 bushels*	*1,000 bushels*	*1,000 bushels*	*1,000 bushels*	*Bushels*	*1,000 bushels*
Pre-war average: [4]							
1909–1913	619	16,001	71,118	48,005	[5] 47,112	6.19	+893
Post-war years: [6]							
1921–22	665	17,190	45,898	24,893	24,138	2.99	[7] +755
1922–23	635	16,415	48,490	26,942	27,343	3.36	[7] −401
1923–24	646	16,699	49,024	28,302	27,372	3.33	[7] +930
1924–25	612	15,820	56,406	34,118	33,509	4.05	[7] +609
1925–26	644	16,647	84,859	60,372	59,250	7.08	[7] +1,122
1926–27	619	16,001	68,880	45,396	40,491	4.80	[7] +4,905
1927–28	642	16,596	73,666	49,367	46,916	5.51	[7] +2,451
1928–29	655	16,932	47,280	25,620			

[1] 25.85 bushels per acre (*10, p. 27*).
[2] 10 per cent of gross production deducted for decay and other losses and seed for following year subtracted from production for stated year, except average for 1909–1913, and annual 1928–29.
[3] For populations, see Table 8.
[4] Acreage and production calculated from Magyar Statisztikai Évkön. 1909–1913.
[5] Human consumption, 4.3 bushels per capita (*1, p. 515*). Industrial and livestock consumption, 30 per cent of net production, or 14,401,500 bushels.
[6] Acreage and production 1921–1928 from official records of U. S. Department of Agriculture, Bureau of Agricultural Economics.
[7] Net imports indicated by (−) and net exports by (+) for calendar years from Internatl. Yearbook Agr. Statis. 1924–25 and 1927–28.

The acreage of potatoes was increased during 1921, 1922, and 1923; yet net production was only about half of the pre-war normal because of climatic conditions and the low quality of seed potatoes employed. Before the World War it had been customary to renew seed potatoes every two or three years with importations from Germany or Slovakia; but after the war this practice was discontinued until 1922. In this year and in 1923, the Government distributed seed potatoes from Germany and Poland, gratis, on the condition that the growers would turn over to the Government for further distribution a quantity of potatoes from the new crop equal to one and one-half times the quantity of seed potatoes received.

It is probable that the yields from 1924 to 1927, which were higher than those of the three preceding years, were somewhat benefited by this improvement in seed. However, these four seasons were favorable to the development of potatoes, and the 1925 and 1927 net production exceeded the pre-war average. Up through 1924 disappearance of potatoes was far below the pre-war average; nevertheless, with the exception of 1922, potatoes were exported each year.

There are seven starch factories and five large distilleries in Hungary. These factories, which use wheat, corn, and rice as well as potatoes, worked only part time in 1924. The starch factories worked at about one-third capacity and the distilleries at about one-tenth capacity. It is probable that few potatoes were fed to stock during these years and that human consumption was also reduced.

In 1925 the use of potatoes was probably a little above the pre-war normal, and 1,122,000 bushels (net) were exported abroad. The crop was of record proportions, reaching 60,372,000 bushels (net), as compared with an average of 48,005,000 bushels during 1909–1913. The cheap price of Hungarian potatoes in the fall and winter of 1925–26 stimulated demand from foreign countries, and 4,987,000 bushels gross were exported during the calendar year 1926. This remarkable rise in exports followed heavy purchases (2,737,000 bushels) by Austrian distilleries. Czechoslovakia took 1,246,000 bushels; Greece, 501,000 bushels; Switzerland, 171,000 bushels; Yugoslavia, 127,000 bushels; Italy, 108,000 bushels; Germany, 79,000 bushels; and other countries, 18,000 bushels.

Hungary imported 81,915 bushels during 1926 from Austria and Yugoslavia.

The crop of 1927 exceeded that of 1926 by 3,971,000 bushels (net); yet the exports were less than those of the previous season, totaling 2,662,000 bushels gross. The greatest part of these exports, 893,000 bushels, went to Austria. Exports to other countries were as follows: To Greece, 496,000 bushels; to Czechoslovakia, 486,000 bushels; to Yugoslavia, 466,000 bushels; to Italy, 173,000 bushels; to Germany, 142,000 bushels; and to other countries, 6,000 bushels.

Hungary imported 211,000 bushels of potatoes in 1927 from Yugoslavia, Rumania, and Italy.

Domestic trade in potatoes was slack throughout 1927, and it is remarked as a new phenomenon by experts that the consumption of potatoes, in recent years, has diminished considerably (*3*).

SUGAR BEETS AND BEET SUGAR

Just as the beet-sugar industry of the Austrian Empire was financed and controlled largely from Vienna, so in the former Kingdom of Hungary this industry was controlled by a few banks in Budapest and one or two financially powerful families. The 31 [27] factories and refineries located in the old Kingdom of Hungary were closely affiliated with the 192 [27] factories located in the old Empire of Austria. Most of the former Hungarian factories were situated outside the present frontiers of Hungary. Hence, when the country was partitioned, following the treaty of Trianon, 8 factories in Slovakia went to Czechoslovakia, 2 in Transylvania went to Rumania, 4 in Voivodina and 1 in Croatia and Slavonia went to Yugoslavia, and 3 in Burgenland went to Austria. Hungary retained 11 factories, producing both raw and refined sugar, and 2 refineries.

During the five sugar seasons September 1, 1909, to August 31, 1914, the 11 factories [28] now located in Hungary worked on the average

[27] The number of factories in operation during any one year varied considerably before the World War. During the sugar season 1913–14 there were 31 factories reported to be in operation in Hungary and 187 in operation in Austria, where 5 factories did not report operations during that season.

[28] Two factories, one at Sarkad in the Comitat of Bihar and one at Ercsi in Fijer Comitat, operated only the last two seasons of this period, as is noted in Table 36.

1,607,914 short tons of beets and produced 222,306 short tons of raw sugar, as is indicated in Table 36.

TABLE 36.—*Sugar beets worked and sugar produced at factories in operation in Hungary, present boundary, average 1909–10 to 1913–14*

Comitat and site of factory	Sugar beets worked at factory	Sugar produced in terms of raw sugar
	Short tons	*Short tons*
Bihar, Sarkad	[1] 139,537	[1] 18,436
Csanad, Mezohegyes	175,077	23,549
Fijer, Ercsi	[1] 91,789	[1] 11,857
Heves, Hatvan	301,605	44,469
Komaron, Acs	134,447	19,248
Nograd, Selyp	121,924	15,434
Somogy, Kaposvar	147,648	20,269
Sopron, Nagycenk	[2] 68,201	[2] 10,003
Sopron, Petohaza	[2] 69,838	[2] 9,942
Vas, Sarvar	184,051	23,763
Zemplen, Szerencs	[3] 173,797	[3] 25,336
Total	1,607,914	222,306

From Magyar Statisztikai Évkön. 1910 to 1914 Tables on "Fabrication du sucre".

[1] 2-year average 1912–13 and 1913–14.

[2] 3 year average 1909–10 to 1911–12. Not separately stated for the last 2 years.

[3] One-half of the beets worked and sugar produced at 2 factories reported to be in operation in Zemplen in 1912–13 and 1913–14 averaged with the separate data for the Szerencs plant for 1909–10 to 1911–12.

It has been estimated that during 1909–1913 the area planted to sugar beets within the territories now constituting Hungary averaged 131,000 acres and produced annually 1,513,000 short tons of sugar beets. The 11 sugar factories thus worked up annually about 95,000 tons of beets produced in territories outside the frontiers of present-day Hungary. It required on an average 7.233 tons of beets to produce 1 ton of raw sugar during this period, so that had the 1,513,000 short tons of domestically produced beets been put through the sugar factories, they would have yielded the equivalent of 209,000 short tons of raw sugar.

TABLE 37.—*Acreage and production of sugar beets and production of sugar in Hungary, present boundary, average 1909–10 to 1913–14, and annual 1921–22 to 1927–28*

Year beginning September 1	Sugar beets		Raw sugar
	Acreage	Production	Production
	1,000 acres	*Short tons*	*Short tons*
Pre-war average:			
1909–10–1913–14	131	[1] 1,513,000	[2] 222,306
Post-war years [3]			
1921–22	103	598,488	67,096
1922–23	103	783,896	90,259
1923–24	128	951,934	136,073
1924–25	168	1,104,554	222,838
1925–26	163	1,683,665	183,128
1926–27	156	1,592,400	192,998
1927–28	159	1,604,311	205,779
1928–29 [4]	164	1,212,761	220,000

Pre-war acreage and production of sugar beets from U. S. Dept. Agr. Yearbook 1926: 1008. Sugar produced, see Table 36.

Post-war acreage and production of sugar beets and production of sugar from official records of U. S. Department of Agriculture, Bureau of Agricultural Economics.

[1] An additional 95,000 short tons of beets imported from present Rumania, Yugoslavia, and Austrian territory were worked up at the factories of residual Hungary.

[2] Includes the sugar produced from the 95,000 short tons of beets indicated in footnote 1. Using the same yield of sugar per ton of beets as indicated in Table 36 to estimate the total sugar produced from the pre-war production of sugar beets in present Hungary, would be equivalent to 209,000 short tons.

[3] The post-war sugar production figures include sugar produced at a factory in Szolnok built during the war, with a daily capacity of 1,500 short tons, and after 1923 includes a factory established in Budapest in 1923, with a daily capacity of 66 carloads, or 728 short tons of beets daily.

[4] Preliminary.

Aside from the citizens of Budapest and of a few large centers, the rank and file of Hungarians use very little sugar. Unlike the Austrian peasants, who include coffee in their diet, the Hungarian peasants seldom use either tea or coffee. Furthermore, honey is widely employed as the sweetening agent in the ordinary household cooking rather than sugar. The total statistical disappearance of raw sugar in the old Kingdom of Hungary, including Croatia and Slavonia, averaged 15.86 pounds per capita during the sugar season 1909–10; whereas in 1913–14 per capital disappearance reached 24.38 pounds.[29]

During the five sugar seasons ended 1913–14, the average statistical disappearance of raw sugar in the old Kingdom of Hungary was 211,203 short tons. Assuming that the annual per capita consumption of sugar in Budapest was at least equivalent to the household consumption in Vienna (47 pounds per capita) and employing the 1910 population of 880,371, the annual pre-war requirement of the Hungarian capital would have amounted to practically 20,689 short tons. This would indicate that 190,514 short tons were consumed in provincial Hungary, which prorated over the 20,006,116 provincial population gives a rough approximation of about 19 pounds per capita.

The 1910 population of the area comprised within the boundaries of the present Kingdom of Hungary has been estimated at 7,606,971. Assuming that the 6,726,600 provincial inhabitants consumed at least as much sugar as the average of the old Kingdom, the provincial pre-war requirement of residual Hungary would have been approximately 63,903 short tons. Adding the requirement of Budapest, or 20,689 short tons,[30] gives 84,592 short tons, or 22.2 pounds per capita as the average pre-war sugar disappearance of Hungary, present boundaries.

During the season 1921–22, when sugar production decreased to 67,096 short tons, about 10,965 short tons of sugar were imported, and the citizens of Budapest were reported to have resorted to the use of saccharine. After adding the visible supply at the beginning of the season and deducting the visible supply at the end of the season as well as exports during the 12 months, the resultant statistical disappearance was about 74,630 short tons. (Table 38.) Prorating this amount over the 1921 estimated population of 8,065,537 gives an average per capita disappearance of 18.5 pounds.

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[29] This latter figure is only a little more than half of the average pre-war household disappearance of sugar in the territories comprising the present Republic of Austria and including the high consumption center of Vienna, which in 1912–13 was approximately 43.6 pounds per capita.

[30] During the sugar season Sept. 1, 1924, to Aug. 31, 1925, cheap sugar brought provincial consumption up to 51,981 short tons, whereas Budapest consumed 43,684 short tons in terms of raw sugar. (MORGAN, J. H. Cons. Rpt. Aug. 23, 1926.) [Typewritten copy on file in Bureau Agricultural Economics Library.]

TABLE 38.—*Sugar in terms of raw: Approximate supply and distribution of present Hungary, average 1909–10 to 1913–14, and annual 1921–22 to 1927–28*

Item	Average 1909–10 to 1913–14	1921–22	1922–23	1923–24	1924–25	1925–26	1926–27	1927–28
	Short tons	*Short tons*	*Short tons*	*Short tons*	*Short tons*	*Short tons*	*Short tons*	*Short tons*
Visible supply on Sept. 1		[1] 3,657	[1] 7,088			19,671	4,834	8,270
Net production	[2] 222,306	[3] 67,096	[4] 90,259	[5] 136,073	[2] 222,838	[2] 183,128	[2] 192,998	[11] 205,799
Importation		[6] 10,965	[6] 1,028	[6] 162				
Total	222,306	81,718	98,375	136,235	222,838	202,799	197,832	214,069
Exportation			[6] 55,417	[6] 90,145	[7] 108,493	[7] 95,332	[8] 78,599	[12] 84,309
Visible supply on Aug. 31		[1] 7,088			[9] 19,671	[9] 4,834	[10] 8,270	[13] 10,506
Total export and on hand at end of year	[9] 137,714	7,088	55,417	90,145	128,164	100,166	86,869	94,815
Disappearance	[14] 84,592	74,630	42,958	46,090	[7] 94,674	[7] 102,633	110,963	119,254

Refined: raw :: 1:1.14.

[1] Report of Vice Consul Digby A. Willson, Oct. 25, 1922, Budapest.
[2] See Table 37.
[3] Ann. Internatl. Inst. 1922: 48–49.
[4] Magyar Statisztikai Szemle January, 1924: 38.
[5] Maygar Statisztikai Szemle November-December, 1924.
[6] Report of Consul Walter S. Reineck, Dec. 6, 1924.
[7] Hungarian Commerce and Industry in the year 1926 (*2, p. 98*).
[8] From report of Vice Consul John H. Morgan dated Nov. 21, 1927, Budapest.
[9] By difference.
[10] From report of Vice Consul John H. Morgan dated Oct. 20, 1927, Budapest.
[11] From official records of U. S. Department of Agriculture, Bureau of Agricultural Economics.
[12] From Commerce and Industry of Hungary in the year 1927 (*3, p. 126*).
[13] From report of Vice Consul John H. Morgan dated Sept. 20, 1928, Budapest.
[14] Disappearance discussed in text.

It is comparatively easy to keep the production, distribution, and retail sale of sugar under the inspection of Government officials. Also, sugar has a relatively high taxable value in proportion to its bulk, and each of the succession States has fostered its production as a means of building up national income. About January 1, 1921, the Hungarian Government fixed the domestic sales price of sugar and decreed that 47.8 per cent of this price should accrue to the account of the State. At the same time, the Government pledged its sugar revenues thus obtained as security for a reconstruction loan for which Hungary was negotiating abroad.

Thus an indirect tax was levied by the Government on all consumers of sugar through what it designated as Treasury participation.[31] This participation so raised the price of sugar that consumption decreased during the season of 1922–23 to about 43,000 short tons. During the season 1923–24, consumption continued far below normal, and saccharine was widely employed as a substitute. During these years the cost of sugar to the foreign buyer in Hungary was less than that in Czechoslovakia because of the lower exchange rate of the Hungarian crown in terms of foreign currency, and in 1924 the entire surplus of the factories of Hungary is reported to have been bought up by foreign buyers. The equivalent of more than 90,000 short tons of raw sugar was sent abroad during the season 1923–24, the greater portion going to Italy.

[31] Treasury participation amounted to 35.61 per cent of the sales price on Jan. 1, 1923, and rose to 53.5 per cent by December, 1924. Reineck, W. S., Cons. Rpt. Dec. 6, 1924, Bowman, T. D., Cons. Rpt. July 13, 1926. [Typewritten copies on file in Bureau Agricultural Economics Library.]

By December, 1925, the degree of Treasury participation was decreased to 41.4 per cent of the purchase price. Prices remained fairly stable during 1925, and domestic consumption increased rapidly to about 102,600 short tons during 1925–26. As a result, the income to the State was greater than when the higher rate of participation was levied.

On account of the importance of domestic sugar sales as a source of internal revenue and the exports of sugar as a means of reducing the adverse trade balance of the country, the Government has taken every means of increasing sugar-beet production.

Sugar-beet production in Europe has always been an industry essentially associated with large-estate farming. As indicated in Table 1, 89.1 per cent of the sugar-beet acreage in 1926 was planted by farmers operating 142.2 acres or more. Small peasants are not equipped to grow beets as well as are the large operators and do not obtain such large returns per acre. The beets produced by large operators in 1926 represented about 90 per cent of the total crop.

The acreage of sugar beets has increased rapidly since the World War. The 1921–22 crop was produced on 103,000 acres, whereas for 1924–25 a total of 168,000 acres was planted, as compared with an average of 131,000 acres before the war. (Table 37.) The large acreage in 1924 followed material support given to the producers by the manufacturers in the way of loans on favorable terms, enabling the farmers to purchase much-needed implements. There was a falling off in 1925 of 5,000 acres, and in the following year about 7,000 additional acres went out of cultivation. This was the consequence of world overproduction in sugar, the slump in the price of sugar in foreign markets being reflected in a decrease in the prices paid for beets to the growers in Hungary.

The low price of sugar in Hungary during 1925–26 resulted in an increase in domestic consumption. The amount of sugar taxed for home use during the season was equivalent to 102,633 short tons of raw sugar. About 95,000 short tons were exported. The quantity of sugar taxed for home use in Hungary during the season 1925–26 is considerably larger than the estimated pre-war disappearance, but is still only 24.6 pounds per capita, as compared with 36.7 pounds in Austria and 61.2 pounds in Czechoslovakia.

Production of sugar in 1926–27 was reported by the International Institute of Agriculture in Rome at 193,000 short tons. The following year, 1927–28, unofficial estimates placed production at 206,000 short tons, an increase of 6.7 per cent. Exports of sugar in terms of raw sugar amounted to 83,199 short tons in the calendar year 1926, as compared with 84,309 short tons in 1927. This is an increase of only 1.3 per cent.

The export of 1927 did not respond more nearly to the increased production of that year over 1926 because, in the first place, the conditions of the world market were unfavorable, also because domestic consumption increased, so that there remained a relatively smaller proportion of the production available for export than in 1926 (*3*).

In all of the other succession States the acreage of sugar beets shows a tendency to fluctuate with conditions of the world market and the price paid to growers. Particularly is this so in Hungary, because such a large percentage of the area grown is on large-estate lands, whose management is more sensitive to economic changes than is that of peasant lands.

Table 39 indicates the sugar trade of Hungary in terms of raw sugar by countries during the calendar years 1925 to 1927.

TABLE 39.—*Sugar in terms of raw:*[1] *Exports from Hungary by countries, calendar years 1925–1927*

Country	1925	1926	1927
	Short tons	*Short tons*	*Short tons*
Fiume	76, 467	44, 599	55, 717
British India and Straits Settlements	4, 015	22, 619	2, 634
Austria	10, 290	9, 583	9, 970
Bulgaria	2, 965	38	333
Switzerland	0	1, 377	2, 256
Italy	1, 268	0	0
Trieste	5, 240	1, 137	5, 574
Egypt	(2)	848	3, 437
Greece	(2)	785	270
European Turkey	(2)	647	748
Other countries	5, 773	1, 566	3, 370
Total	106, 018	83, 199	84, 309

1925 and 1926 from Statisztikai Havi Közlemények October-December, 1925, and October-December, 1926. 1927 from Commerce and Industry of Hungary in the Year 1927 (*3*).

[1] Refined converted to raw on the basis, raw : : refined : 1.14 : 1.
[2] If any, included in other countries.

According to Vice Consul John H. Morgan,[32] an expansion of the sugar industry of Hungary is not to be expected, as difficulties have been experienced in finding markets in foreign countries. On the contrary, if the difficulties in meeting foreign competition abroad continues, Hungarian manufacturers may be compelled to reduce production.

TOBACCO

Under the Austro-Hungarian Monarchy, the entire tobacco industry from planting to the manufacture of the cured leaf was under the control of the Royal Hungarian Tobacco Monopoly. Naturally, after the segregation of Hungary from the territories ceded to the surrounding succession States, the tobacco industry has continued to be handled as a Government monopoly. The districts included within the boundaries of the present State planted 93,000 acres to tobacco yearly before the World War and produced an average of 111,883,000 pounds during 1909–1913. (Table 40.)

[32] MORGAN, J. H. THE HUNGARIAN SUGAR INDUSTRY. Cons. Rpt. Nov. 26, 1927, 8 p. 1927. [Typewritten copy on file in Bureau Agricultural Economics Library.]

TABLE 40.—*Tobacco: Statistical balance of Hungary, present boundary, average 1909–1913, and annual 1921–1927*

Year	Acreage	Production	Disappearance		Exportable surplus (+) or deficit (−)
			Total	Per capita[1]	
	1,000 acres	*1,000 pounds*	*1,000 pounds*	*Pounds*	*1,000 pounds*
Pre-war average:					
1909–1913	93	111,883	19,244	[2] 2.53	+92,659
Post-war years:					
1921	49	40,705	40,684	5.04	[3] +21
1922	44	34,392	32,334	3.97	+2,058
1923	38	29,762	26,838	3.26	+2,924
1924	38	38,045	33,800	4.08	+4,345
1925	38	37,699	37,637	4.50	+62
1926	[4] 59	[4] 57,823	65,016	7.70	−7,193
1927	58	69,095	68,224	8.01	+871

1921–1925 acreage and production from U. S. Dept. Agr. Yearbook 1924: 825–826; 1925: 1025–1027; 1926: 1029.
1927 International Yearbook of Agricultural Statistics 1927–28.

[1] For populations see Table 8.
[2] Average 1909–1913 per capita amount of tobacco sold in the old Kingdom of Hungary from Magyar Statisztikai Évkön. 1911: 194; 1914: 132.
[3] Net exports (+) and net imports (−) 1921 to 1927 from Statisztikai Havi Közlemények 1921–1927.
[4] Commerce and Industry of Hungary in the Year 1927 (*3*).

Two types of tobacco are grown in Hungary—a heavy-leaf tobacco and a small-leaf variety used for cigarettes and smoking tobacco. The latter variety is not of outstanding importance. Only 271 acres, which produced 193,000 pounds, were planted in 1926. There were seven local varieties of broadleaf tobaccos of commercial importance. These varieties and their acreage and production in 1926 were as follows: Debrecen, 30,419.4 acres, producing 30,911,000 pounds; Tisza, 17,039 acres, producing 15,857,000 pounds; Erti, 4,425 acres, producing 5,595,000 pounds; Szeged, 2,529 acres, producing 2,111,000 pounds; Szolnok, 1,897 acres, producing 1,149,000 pounds; Szentandras muscat, 380 acres, producing 260,000 pounds; and Kapa, 1,871 acres, producing 1,746,000 pounds. The last-named variety is a coarse, low-grade tobacco. It is called kapa (Hungarian for hoe) because it is smoked chiefly by farm laborers. Some of this tobacco is used for making cigars, but most of it goes into cigarettes and pipe tobacco. One sort of tobacco, Debrö, was grown experimentally, only 1.4 acres were planted, which produced 1,000 pounds.

In all, 58,833 acres of tobacco produced 57,823,000 pounds of leaf in 1926. The acreage planted to tobacco is regulated by the monopoly to meet domestic requirements and to afford only such surplus as can be exported profitably.

During the fiscal year 1926–27 the monopoly manufactured 26,577,000 pounds of tobacco, as compared with 26,949,000 pounds in 1925-26. The native tobacco employed was 20,627,000 pounds in 1926–27 as compared with 21,068,000 pounds during the preceding year. In 1926–27 the monopoly used 5,950,000 pounds of imported tobacco as compared with 5,881,000 pounds in 1925–26.

The manufactured products included 10,667,000 pounds of common pipe tobacco, 7,820,000 pounds of fine pipe and cigarette tobacco, 252,000 pounds special pipe and cigarette tobacco, and 1,532 pounds of snuff. They also made 35,071,000 special and 2,154,602,000 common cigarettes, as well as 3,344,000 special and 91,279,000 common cigars.

INTERNATIONAL TRADE IN TOBACCO

Tobacco is imported into Hungary only by the Royal Hungarian Tobacco Monopoly. Leaves for cigar binders and wrappers are purchased exclusively at the auctions of Amsterdam and Rotterdam. Fillers (Havana, Brazil, Cuba, Java, etc.) are purchased chiefly on the basis of offers submitted to the Regie (monopoly) through German agents. * * * Tobacco for the manufacture of pipe and cigarette tobacco (Turkish, Bulgarian, Greek, and Russian) are purchased by agents of the monopoly who are sent out after offers have been received from producers or middlemen in these countries.[33]

This trade does not affect the farmers of North America directly because no Hungarian tobacco is sold in the United States and very little tobacco from the United States has been purchased by the Hungarian Tobacco Monopoly since the World War. A small quantity of Virginia and Kentucky tobacco was purchased in 1922. This supply was sufficient to meet the needs of the monopoly until 1925, when the last of these purchases was worked up into pipe tobacco. Because the quantity of United States grown tobacco used in Hungary is very small, it is probable that the depleted stock will be replenished by purchases in European markets rather than by purchase from the United States direct.

During 1927 Hungary imported 7,886,075 pounds of raw tobacco, as compared with 10,433,270 pounds the previous year, and 253,309 pounds of manufactured tobacco during 1927, as compared with 22,266 pounds in 1926. The countries of origin are indicated in Table 41.

TABLE 41.—*Tobacco: Imports and exports of Hungary by countries, calendar years 1926 and 1927*

Country	1926		1927	
	Imports	Exports	Imports	Exports
Raw:	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Bulgaria	5, 024, 064		4, 972, 035	
Asiatic Turkey	3, 465, 190		1, 592, 162	
Greece	1, 118, 394		146, 386	
Italy	513, 672		345, 240	
Holland	197, 311	253, 750		
Germany	114, 639	276, 015	224, 869	336, 643
Austria		1, 247, 142		3, 253, 990
Poland		783, 956		2, 667, 125
Belgium		435, 409		322, 533
France		188, 493		113, 757
Czechoslovakia		55, 115		1, 956, 362
Netherlands			605, 383	46, 076
Egypt				60, 406
Total	10, 433, 270	3, 239, 880	7, 886, 075	8, 756, 892
Manufactured:				
Great Britain	15, 653		78, 925	220
Egypt	3, 307		115, 301	
Belgium	2, 645			
Denmark		220		882
European Turkey	(a)	(a)	55, 335	
Switzerland	(a)	(a)		2, 867
Other countries	661		3, 748	220
Total	22, 266	220	253, 309	4, 189

From Statisztikai Havi Közlemények, October-December, 1926, and October-December, 1927.

[a] If any, included in other countries.

HORTON, G. REPORT CONCERNING THE CULTURE, PRODUCTION, AND TRADE ON TOBACCO. Cons. Gen. Rpt. Jan. 23, 1921, 10 p. 1921. [Typewritten copy on file in Bureau Agricultural Economies Library.]

The imports of manufactured tobacco were more than ten times as great in 1927 as in the previous year, chiefly on account of the ease of purchasing special products abroad. In 1928, 300 carloads (about 6,613,800 pounds) were sold in Amsterdam. Several carloads of cigarette and pipe tobacco are reported to have been sold in China, Formosa, and Japan.

COTTON

Since the World War, 43 new textile plants have been put into operation in Hungary. Most of these were cotton mills in small country centers. From 1918 to 1924 the number of spindles had increased five times. It was reported that there were about 93,000 spindles in 1924. During that year 8,240 looms were reported to be in operation. According to Vice Consul Morgan,[34] the National Association of Textile Manufacturers reports the number of cotton spindles as 120,000 and the number of looms as approximately 10,000 in 1926. Production increased considerably during the year, enabling the mills to supply about 50 per cent of the domestic demand, as compared with 44 per cent during the previous year.

The bulk of the cotton employed in the Hungarian textile industry is supplied directly by the United States. (Table 42.)

TABLE 42.—*Cotton, raw, including waste: Imports and exports of Hungary by countries, 1926 and 1927*

[In thousand pounds—i. e., 000 omitted]

Country	1926		1927	
	Imports	Exports	Imports	Exports
United States	10,147		12,697	
Germany	552	77	1,027	301
Austria	515	670	920	912
British India and Straits Settlements	359		1,568	
Czechoslovakia	115	107	285	211
Egypt	95			
Switzerland	82	2	152	
Holland	75			
Brazil	67			
Netherlands	(1)	(1)	73	9
Other countries	33	64	48	39
Total	12,040	920	16,770	1,472

From Statisztikai Havi Közlemények, October-December, 1926, and October-December, 1927.

1 If any included in other countries.

FODDER PLANTS

The farmers of western Hungary, who were within easy rail and water communication with Vienna and Budapest and who were not far removed from Prague, Munich, and central Europe, were accustomed, before the World War, to buy up lean, grass-fed cattle and other livestock in the eastern part of the old Kingdom and stall feed these animals preparatory to slaughter. They had free access not only to the districts producing the animals to be fed but, also, to districts producing surpluses of feeding stuffs with which to do the

34 MORGAN, J. H. COTTON SURVEY IN HUNGARY FOR THE 12 MONTHS ENDING JULY 31, 1927. Cons. Rpt. Sept. 10, 1927, 4 p. 1927. [Typewritten copy on file in Bureau of Agricultural Economics Library.]

feeding—corn from Voivodina, Banat, and Crisana, hay from the Seven Mountain region, and potatoes from Slovakia.[35]

When Hungary was set off as a segregated State by the treaty of Trianon, the feeding centers about Budapest and in western Hungary were cut off not only from feeders but also from supplemental feeds. In fact the feed supply for such animals as would normally be carried on the farms of central Hungary was placed in jeopardy. There has been a tendency, even before the World War, to constrict the acreage of natural meadows and pastures and to depend upon cultivated field crops for feeding stuffs. In 1868, meadows and pastures constituted 28.3 per cent of the farm lands of the old Kingdom of Hungary. This proportion had dropped to 25 per cent by 1885; to 22.67 per cent by 1895; and, by 1911, to 21.93 per cent. (*14, p. 17.*)

The percentage of all lands under meadows and pastures in 1911 in the districts comprising present-day Hungary has been estimated at 18.4 per cent. In 1921, out of a total area of 22,921,000 acres, 4,147,000 acres or 18.1 per cent was under meadows and pastures. By 1927, adjustments of boundaries brought the total area up to 22,970,000 acres, but the percentage of meadows and pastures remained unchanged, totaling 4,154,000 acres. (See Table 2.)

It has been suggested that the land reform would probably have a tendency to decrease the area of meadows and pastures because, as is indicated in Table 43, the proportion of grazing lands to total acreage was much less on small peasant holdings than on the large estates.

TABLE 43.—*Percentage of farm acreage in plowland and in pastures in 1895*

Utilization of land	Percentage of farm land classified by—			
	Very small holdings	Small holdings	Middle-sized holdings	Large estates
	Per cent	*Per cent*	*Per cent*	*Per cent*
Plowland	63.6	78.1	57.6	33.3
Pastures	3.2	5.3	12.0	13.6

Die Boden Reform und ihre Wirkung auf die Entwicklung der Ungarischen Landwirtschaft. (*14, p. 18.*)

Between 1921 and 1927 there was no indication of a diminution of meadows and pastures. The meadows and pastures of Hungary in 1923 covered about 18 per cent of the total area of the country, as compared with 18.4 per cent in Czechoslovakia (1925) and 28.2 per cent in Austria (1923). The grazing on the pastures and meadows of Hungary is always problematical and subject to wide fluctuations on account of drought and flood.

It has been necessary to increase the areas under artificial forage crops to maintain the flocks and herds of Hungary at their pre-war level or at the level requisite to the highest possible development of the animal industry.

[35] Voivodina and the western part of Banat are now incorporated in Yugoslavia. The eastern part of Banat, Crisana, and the Seven Mountain region are now parts of the administrative district of Transylvania in Rumania. Slovakia is part of Czechoslovakia.

According to Ludwig Leopold (*9, p. 152*) the area of clover in Hungary in 1926 was 34 per cent above the pre-war normal; that of alfalfa 39 per cent above normal; that of sanfoin 92 per cent; and that of hirsengrass (millet grass) 39 per cent above normal.

The Hungarian peasants value forage plants not only because they supply feed for livestock whose manure is indispensable in maintaining the fertility of the soil but because they understand that such crops as clover improve soil conditions chemically and such crops as roots and potatoes improve them physically. The number of farm animals that Hungary can maintain is limited to the carrying capacity of the meadows and pastures as supplemented by cultivated forage and fodder plants and grains or by the importation of such feeding stuffs. Eastern Hungary is a plains country (the Alföld) and with the improvement of the pastures and meadows could carry considerably more livestock than is now found in this part of the country. However, the improvement in the livestock industry of Hungary may follow the trend begun before the World War and express itself in greater weight and production per animal—in an increase in quality rather than in numbers.

Hungary exported 12,769 short tons of hay in 1927, as compared with 10,078 in 1926. In both years the bulk of the export went to Czechoslovakia and Austria.

TABLE 44.—*Forage and fodder plants: Acreage and production in Hungary, 1924–1927*

Classification	1924		1925		1926		1927	
	Acreage	Production	Acreage	Production	Acreage	Production	Acreage	Production
	Acres	*Short tons*	*Acres*	*Short tons*	*Acres*	*Short tons*	*Acres*	*Short tons*
Forage beets	237, 485	1, 957, 704	254, 041	2, 849, 204	243, 991	2, 680, 892	219, 591	2, 709, 996
Forage beets (mixed crop)	5, 136	12, 658	5, 755	61, 256	6, 719	66, 474	8, 426	88, 355
Forage pumpkins	15, 965	113, 033	16, 640	172, 811	16, 279	165, 178	16, 674	169, 432
Sanfoin	88, 071	98, 492	92, 252	117, 121	82, 685	119, 307	84, 214	99, 211
Alfalfa	459, 932	778, 059	453, 540	804, 234	434, 118	787, 877	422, 773	689, 709
Alfalfa (mixed crop)	6, 395	11, 110	6, 516	12, 176	8, 999	16, 310	10, 213	17, 066
Corn fodder	194, 095	2, 221, 084	192, 466	2, 279, 231	193, 178	2, 605, 841	185, 799	2, 209, 065
Moha [1]	61, 429	72, 137	63, 638	86, 089	72, 269	101, 367	72, 642	95, 197
Winter peas and fodder rye	30, 986	45, 723	30, 907	47, 007	27, 070	47, 339	23, 581	38, 991
Clover	311, 195	431, 450	367, 499	541, 680	364, 707	594, 060	393, 065	559, 199
Vetches	113, 728	139, 639	115, 237	142, 954	96, 915	127, 519	99, 957	124, 429
Vetches and oats	358, 162	461, 987	383, 507	526, 308	365, 075	526, 529	365, 029	512, 371
Total sown grasses and other forage	1, 874, 048	6, 376, 076	1, 969, 727	7, 643, 071	1, 896, 290	7, 838, 693	1, 913, 355	7, 313, 031
Permanent meadows and pastures	4, 150, 292		4, 133, 847		4, 153, 855		4, 151, 332	

From Internatl. Yearbook Agr. Statis. 1925–26: 48–49; 1926–27: 48–49; 1927–28: 48–49.

[1] A variety of Italian millet.

LIVESTOCK

The scientific breeding and feeding of livestock in the Kingdom of Hungary was almost exclusively an industry developed by the initiative of the large landed proprietors until 1880. The Government offered assistance and encouragement by paying the freight and subsistence of breeding animals en route, by advancing noninterest-bearing loans to breeders, and by giving advice as to breeds and methods. Later, the Government took active steps to foster the animal industry of the Kingdom. In 1894 a law of the rural police instituted a technical section in animal husbandry in the Ministry of Agriculture and undertook to regulate the following: (1) The number of animals to be grazed on village pastures; (2) the adaptation of breeds to each locality; (3) the number of sows bred to a single male; (4) the quality of the male as to breed characteristics. It also issued certificates to owners of sires that were to be employed by the public. Advances in animal industry were more easily effected among the Magyar nobles and peasantry in the counties west of the Danube and on the Alföld, than among the subject peoples: Slovaks, Rumanians, Croats, and others who had been crowded back into the surrounding foothills when the nomadic hordes from the steppes of Russia invaded the upper Danube Basin.

The Avars, the Francs, the Huns, the Slavs, and the Germans during their migrations had each brought their own particular native breeds of livestock with them from western Europe, or Russia or Asia to the Alföld of the Danube, and these had intermingled with the domestic animals of the aboriginal Celts. The Rumanians, during the early centuries of the Christian Era, had acquired several breeds from the Mediterranean Basin and Asia, including water buffaloes from India, so that when the Magyars arrived on their fast ponylike horses, followed more deliberately by their wagon trains of slowly plodding oxen, they found a variety of flocks and herds on the Danube steppes. These primitive breeds of farm animals persisted in Hungary until well toward the close of the last century, and vestiges of them are still to be found in the foothills and mountains of the surrounding succession States. But on the plains now comprised within the frontiers of Hungary the general-purpose low-grade breeds had been rapidly giving place to the purebred specialized strains of livestock introduced from the west.

These changes were accelerated by the direct participation of the Hungarian Government, after 1880, and from then until the outbreak of the World War the systematic upbuilding of the animals found not only on large estates but also on small peasant land holdings in the Comitats now constituting Hungary was more intensely organized, perhaps, than in any other part of Europe. Animal industry rivaled crop production, and the value of the export of live animals, meat, fat sides, hides, and other animal products practically equaled the export value of field-crop products.

In the counties west of the Danube animal husbandry is intensive. Animals are stall-fed, and large areas are cultivated to forage and fodder crops. This is in sharp contrast to the extensive cattle grazing on the plains of the Alföld east of the Danube, where, on account of the lack of moisture or the sterility of the soil (soda soils), whole regions are unsuited to field-crop production. Here are found large herds of cattle, horses, and sheep, which on the whole afford a source of profit but which suffer severely in dry years.

At the outbreak of the World War the animal industry of Hungary was at its height. Breeders and feeders of the central plain had easy access to the large surpluses of corn produced in Banat and Crisana, now parts of Yugoslavia and Rumania, and to the supplies of hay produced in the Seven Mountain region, now incorporated into Rumania, and to the supplies of potatoes grown in Slovakia.

Hungary is cut off from its former sources of feeding-stuff supplies by the frontiers of three newly formed succession States—Czechoslovakia, Yugoslavia, and Rumania—and is thus handicapped by customs barriers from obtaining feeds to which it had free access before the World War, to supplement the production of the meadows and pastures found in the Alföld.

There were 6,722,000 (*10, p. 8*) acres of meadows and 8,327,000 acres of pastures in the old Kingdom in 1911, as contrasted with 1,706,000 acres of meadows and 2,523,000 acres of pastures within the present boundary of Hungary. There were, on the average, in 1911 throughout the old Kingdom of Hungary 51 sheep, 43 swine, 41 cattle, and 13 horses to each 100 acres of grassland or 1.5 animals per acre. This is in contrast to the conditions in the counties now comprising Hungary, in which in 1911 were found 56 sheep, 76 swine, 47 cattle, and 21 horses per 100 acres of meadows and pastures or an average of 2 animals per acre.

Even before the World War (in 1911), it was not possible to maintain the numbers of livestock found within the Comitats now comprising Hungary without recourse to supplementary feeding on an extensive scale and the purchase of corn, hay, and potatoes in other parts of the former Kingdom. Since the war, although the numbers of livestock has been considerably below the 1911 level and although the areas under forage and fodder plants have been increased, it has been a grave problem to obtain feedingstuffs sufficient to maintain the animals on Hungarian farms in proper condition.

In 1923 there was such a shortage of forage for livestock that the Minister of Agriculture took into serious consideration the question of increasing the area of pasture lands in connection with the land reform. Many farmers were reported to have sold their surlpus cattle to butchers, retaining only such animals as were required for breeding and spring work. The total number of horses, cattle, sheep, and swine carried over at the end of that year was 6,354,000, or about 1.5 per acre of meadows and pastures. A small quantity of corn had to be imported during the year to carry even this number through the summer.

The crop and pasture lands are limited and these in turn limit the numbers of live animals that can be maintained. It is probable that in good years Hungary could produce many more animals than were carried over at the end of 1911. However, on account of the capriciousness of the climate, there would be considerable danger in carrying the maximum number of live animals the country's forage supply would support. The peasant farmer would always be in danger of having to dump his animals upon the market at a possible loss whenever there was a drought or a shortage from any other cause.

The pre-war numbers of livestock in the Comitats now comprising Hungary, as indicated by the census of 1911, had not been reached by the spring of 1928. It must, however, be borne in mind that the census of 1911 included many animals on feed (young stock and lean animals) that were bred in territories outside the boundaries of present Hungary and that had been shipped to the farms about Budapest and near Vienna for finishing before final marketing for slaughter. On the other hand, the 1911 numbers do not represent the maximum number of animals that can be carried on Hungarian farms. If the utilization of forage and fodder can be sufficiently increased these numbers may represent only a fair average about which livestock numbers in Hungary may probably fluctuate. This is more than sufficient for the country's domestic needs and admits of a considerable export of horses, cattle, sheep, hogs, meats, and other animal products to western and northern markets.

In ancient times, no animal was in such high favor in eyes of the Magyars as the horse; later, on account of the high price of wool, the sheep "walked on feet of gold." At the outbreak of the World War, the modern Hungarian farmers kept pace with the Americans and valued their farm animals in the following order: Swine, cattle, horses, and sheep.

Only 15.5 per cent of the swine were found on large holdings of 284.5 acres or more. These large farms specialized in the production of wool and mutton and possessed 71.2 per cent of the sheep. As indicated in Table 6, 552,620 small landowners owned 679,343 horses, averaging more than 1 horse to the farm, as well as 1,200,110 cattle, or more than 2 to the farm. The production of animals and animal products in Hungary was outstandingly an industry of the small farmer.

SWINE

It is probable that the aboriginal dwellers in the Alföld as well as those of the hill country west of the Danube possessed half-wild swine at the time of the advent of the Magyars. It is also probable that the thrifty Magyars brought with them swamp and mountain swine plundered from the villagers of the Carpathians and the lowlands to the east. In any case, two well-defined breeds of hogs were found in Hungary at the beginning of the nineteenth century. One of these called Bakony was found west of the Danube, where hogs were grazed in herds in the oak and beech forests as far west as Styria in Austria and as far south as the Sava River on the Bosnian frontier. The other breed, known as Szalonta, was found on the Alföld east of the Danube as far as the region of Seven Mountains. (See footnote 35.) Both of these breeds were rangy, razorback, meat hogs—late maturing and not very prolific.

The modern swine industry of Hungary dates from 1838, at which time one of the leading Hungarian agriculturists, Prince-Palatin Joseph, brought to his estates in Kisjeno 2 boars and 10 sows of a breed called Angolica (Mangolica)[36] which he obtained from the Topschider domains of the Serbian Prince Milos. This breed was prolific, and the rapidity with which it laid on fat was astounding to the Hungarians. At 1 year of age, boars weighed from 154 to 187

[36] The name suggests that this breed was of Mongolian origin.

pounds and sows 143 to 176 pounds. The Mangolicas were so well adapted to the conditions found in the wooded hills west of the Danube that, 17 years after their introduction into Hungary, the Bakony breed had disappeared. During the next 20 years, Mangolicas had practically replaced the Szalontas on the Alföld east of the Danube.

Such an impetus was given to hog production that between 1857 and 1895 swine numbers in Hungary (not including Croatia and Slavonia) increased from 3,572,000 to 6,447,000. During the next 16 years there was little change, the census of 1911 showing 6,415,000 swine in the old Kingdom.

About half the swine in the old Kingdom were found within the Comitats now comprising Hungary. (Table 45.)

TABLE 45.—*Swine: Trend of numbers on hand in the old Kingdom of Hungary for specified years, 1857–1911, and in Hungary, present boundaries, 1911 and 1920–1928*

Territory	Year	Total swine	Per 1,000 acres [1]	Per 1,000 inhabitants [2]
		Thousands	*Number*	*Number*
Old Kingdom of Hungary (excluding Croatia and Slavonia)	1857	3, 572	51. 1	[3] 302. 0
	1870	3, 072	43. 9	226. 2
	1884	4, 804	68. 7	334. 5
	1895	6, 447	92. 2	404. 4
	1911	6, 415	91. 8	351. 2
Hungary, present boundary	1911	3, 213	139. 8	422. 4
	1920	2, 653	115. 4	333. 9
	1921	2, 563	111. 5	319. 1
	1922	2, 473	107. 6	305. 0
	1923	2, 133	92. 8	260. 5
	1924	2, 458	106. 9	298. 3
	1925	2, 633	114. 6	314. 6
	1926	2, 520	109. 6	298. 4
	1927	2, 387	103. 9	280. 2
	1928	2, 662	115. 8	309. 7

1857, from Le Porc en Hongrie 1900: 45.
1870–1911, from Magyar Statisztikai Évkön. 1872: 120; 1900: 100; 1913: 96.
1911, new boundaries calculated from Magyar Statisztikai Évkön. 1912: 131, 137.
1920, furnished by the Royal Hungarian Ministry of Agriculture.
1921, estimated by interpolating the decrease between 1920 and 1922.
1922–1926, from Magyar Statisztikai Szemle, May–June, 1925, January, 1926, and January, 1927.
1927, from Internatl. Crop Rpt. and Agr. Statis., November, 1927, (n. s.) 18: 614.
1928, from report of Vice Consul J. H. Morgan, Oct. 24, 1928, Budapest.

[1] Pre-war area = 69,898,000 acres from Magyar Statisztikai Évkön. 1913: 11, and post-war area = 22,983,000 acres from Statesman's Yearbook, 1926.
[2] Populations = 1870, 13,579,129 from Statis. Jahrb. Ungar. 1873: 22.
1884, 14,363,012 from Statis. Jahrb. Ungar. 1884: 5.
1895, 15,940,327 from Magyar Statisztikai Évkön. 1895: 65.
1910, 18,264,533 from Magyar Statisztikai Évkön. 1912: 19.
1910–1928 new boundaries, see Table 8.
[3] From Le Porc en Hongrie 1900: 45.

Before the World War, 90.2 per cent of the swine in the Comitats now comprising Hungary were Mangolicas. Out of a total of 3,213,000 hogs in 1911 only 314,000, or 9.8 per cent were Yorkshires or other western-European breeds of the bacon type. Aboriginal types of hogs are not to be found in Hungary, although such primitive types still persist in the highlands of Austria, Czechoslovakia, Rumania, Bulgaria, and south Yugoslavia.

The production of pork and lard in Hungary is of special interest to the farmers of the United States because of the competition of these products with American pork and pork products on the markets of central Europe.

FEEDING AND MARKETING

The swine owned by small farmers run around the farmyards and act as scavangers. The 552,620 owners possessing farms up to 284.4 acres held 1,819,921 swine in 1911, or an average of 3 to 4 hogs each. (Table 6.) When grain is cheap the peasant turns his cereals into pork, and markets his produce in this form. When pork is cheap or cereals dear, the peasant lets his swine shift for themselves and markets his product in very lean condition. There is thus no uniformity in the character of hogs produced by the peasants under such conditions, and for this reason there is great variation in size and quality from year to year and from household to household.

In 1911 there were 273,880 landless owners of swine who maintained 896,075 hogs. Most of these owners were householders who fed 1 or 2 hogs for home use, but many owned small establishments for fattening pigs with purchased feed. Most of these establishments were in the vicinity of Budapest or in western Hungary between Budapest and Vienna or Prague. But there were several large establishments that handled thousands of hogs each year.

The commercial fattening of swine in the Comitats now comprising Hungary is an ancient industry. During the early years of the eighteenth century, the Serbs drove large herds of swine on foot along well-defined trails through the woods west of the Danube in the direction of Vienna, selling a few here and a few there along the route. They also brought hogs in boats up the Danube. The animals not sold in Hungary eventually found their way into Styria, lower Austria, Bohemia, or even as far up the Danube as Bavaria.

The cultivation of Indian corn during this century increased rapidly, particularly in the lowlands of the Alföld in the southeast, where pork production on a commercial scale was firmly established at the beginning of the nineteenth century. The Serbs, who also produced corn in great quantities and who had swine of superior quality, were practically the sole competitors of the Hungarians until the middle of the last century. At that time, pork and lard from the United States began to appear upon the German markets to the detriment of the corn and hog farmers in both Serbia and Hungary.

From 1870 to 1890, the main business of pork production was conducted at Köbánya, a large establishment near Budapest where, during 1890, more than 640,000 hogs were on feed. Another important establishment was located at Györ, on the Danube between Budapest and Vienna. This establishment was equipped to handle more than 40,000 hogs. During the next 10 years, 8 other establishments, equipped to fatten from 15,000 to 40,000 hogs each came into prominence, and the significance of Köbánya diminished so that by 1900 only 170,000 hogs were under feed at this plant.

Köbánya handled about 90,000 native hogs and 80,000 Serbian hogs in 1900, Rumania having dropped out as a source of lean swine. When the Austria-Hungarian agricultural protective tariff went into effect in 1906, Serbia was shut out of the Hungarian market, and from then on Köbánya handled only native stock. After the loss of Serbian lean swine Köbánya was unable to obtain sufficient native hogs and until the outbreak of the World War the number of hogs handled during any one year never exceeded 92,300 (Table 46), although the total number of swine commercially slaughtered or exported from the old Kingdom of Hungary during 1909–1913 averaged about 2,191,000.

TABLE 46.—*Swine: Numbers received at the feeding institution in Kōbánya from specified countries, 1870, 1880, 1890, and 1900–1913*

Year	Hungary	Serbia	Rumania (old Kingdom)	Galicia	Total
	Number	*Number*	*Number*	*Number*	*Number*
1870	318, 700	216, 160	54, 000		588, 860
1880	416, 440	30, 050	26, 573		473, 063
1890	502, 764	136, 787	1, 879		641, 430
1900	87, 977	82, 295			170, 272
1901	88, 210	108, 306			196, 516
1902	81, 398	148, 857			230, 255
1903	62, 069	136, 985			199, 054
1904	48, 923	151, 929			200, 852
1905	64, 124	114, 020			178, 144
1906	81, 008	[1] 62, 181			143, 189
1907	83, 702				83, 702
1908	89, 006				89, 006
1909	90, 732				90, 732
1910	86, 957				86, 957
1911	67, 700			350	68, 050
1912	88, 374				88, 374
1913	92, 272				92, 272

1870–1890 from Le Porc en Hongrie 1900: 84.
1900–1913 from Magyar Statisztikai Évkön. 1900 to 1908 and 1913.

[1] 7 months only. There were no shipments of hogs from Serbia to Hungary after July, 1906, at which time the agricultural protective tariff of the Austro-Hungarian Monarchy went into effect. The bitter feeling engendered in Serbia at the abrupt exclusion of Serbian hogs from the Austria-Hungarian markets continued until the World War.

During the 5-year period ended in 1913, the slaughterhouses of the old Kingdom of Hungary including Croatia and Slavonia dressed an average of 1,597,586 hogs, in addition to which 593,635 [37] live hogs were shipped abroad each year. The yearly commercial turnover of hogs before the World War thus averaged about 2,191,000 head or about 29 per cent of the numbers of swine reported on Hungarian farms including Croatia and Slavonia in 1911. This does not include animals slaughtered for home use, of which there is no record.

Before the World War the hog-feeding industry was concentrated in two general districts: (1) In the counties of west Hungary between the Danube and the Austrian frontier, and (2) in the southeastern corn belt comprising eastern Croatia and Slavonia and Voivodina (now in Yugoslavia), and Banat and Crisana (now parts of Rumania). Since the war, it has been difficult for the commercial feeding establishments to obtain lean hogs from their former sources of supply, from which they have been shut off by Rumanian and Yugoslavian customs barriers. The Comitats comprising Hungary were dependent upon former outlying districts not only for lean hogs but for corn and other feeds as well. Free trade in the former markets of Vienna, Prague, and many other cities to the west and north is a thing of the past. Sales of hogs and pork products in the Provinces now comprising Austria and Czechoslovakia are hampered by tariff restrictions and questions of the fluctuating value of the currencies of these countries. Therefore, it will be very difficult, if indeed it is possible, for the former swine-fattening industry of Hungary to be reestablished upon a plane of its pre-war magnitude.

[37] During this period Austrian records show that 438,168 live hogs received at Vienna originated in Hungary and Croatia Slavonia. Galicia, now a part of Poland, shipped 373,439 hogs to Vienna each year during these 5 years.

In 1920 there were 2,653,000 swine in Hungary, as compared with 3,213,000 in 1911, a decrease of 560,000 head. But a large part of this decrease is accounted for by the fact that there were not such large numbers of swine from the east and southeast in the feed lots about Budapest and west of the Danube as has been normally the case before the World War. The 1920 census figures represent more nearly the swine bred and raised within Hungary than do those of 1911.

During the next three years swine numbers decreased, reaching their postwar minimum of 2,133,000 in 1923. During 1922 and 1923, not enough corn was produced in Hungary to carry the livestock of the country through these two seasons, and 220,000 bushels had to be imported in 1922 and 78,000 bushels in 1923.

In 1924 and 1925, corn production increased to 72,635,000 and 86,496,000 (net) bushels respectively. Swine numbers similarly increased to 2,458,000 in 1924 and to 2,633,000 in 1925. The following year, corn production fell off to 75,074,000 bushels (net), and the number of swine decreased to 2,520,000. In 1927, there was a further decrease in corn to 66,870,000 bushels, accompanied by a decrease in swine to 2,387,000.

There is a general relation between the numbers of hogs carried on farms in Hungary and the production of corn, and the decrease in the corn crop in 1926 was accompanied by heavier marketing of hogs. (Table 47.)

TABLE 47.—*Hogs sold in Budapest, 1924–1927*

Year	Sold in open market	Other reported sales	Total
	Number	*Number*	*Number*
1924	199,423	28,870	228,293
1925	348,358	37,239	385,597
1926	532,691	[1] 52,771	[1] 585,462
1927	421,574	23,450	445,024

Ludwig Leopold (*9*), Commerce and industry of Hungary in the year 1927 (*3*).

[1] Estimated.

In the beginning of 1926 more and more hogs were placed on feed at commercial establishments in the hope of the development of trade with Germany. Corn of the 1925 crop was cheap at first; but, during the season, it became evident that the 1926 crop would be short, and prices rose sharply while the hogs were still on feed. In the meantime the price of fat hogs fell below the price the farmers were asking for lean pigs.

The packing houses of Czechoslovakia took advantage of this situation and bought up 40,427 hogs weighing over 154 pounds each from the estates of Hungarian nobles for conversion into hams and bacon. Austria took 105,579 heavy hogs, and 30 went to other countries.

Hungary exported 753 suckling pigs to Austria in 1926 and 15 to Yugoslavia. A total of 10,890 pigs weighing from 66 to 154 pounds was exported to various countries, as follows: Austria, 9,564; Czechoslovakia, 1,208; Yugoslavia, 105; and Rumania, 13.

The total export for 1926 was 157,694, as compared with 893,192 exported from the old Kingdom of Hungary in 1913. (Table 48.)

TABLE 48.—*Swine: Exports from the old Kingdom of Hungary by principal countries, 1906–1913, and from Hungary, present boundary, 1921–1927*

Year	Austria	Germany	Switzerland	Italy	Czechoslovakia	Other countries	Total
Old Kingdom:	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
1906	424, 122	244	653	10	(1)	130	425, 159
1907	378, 354	114	5, 344	8, 624	(1)	33	392, 469
1908	482, 740	1, 446	3, 156	17, 126	(1)	61	504, 529
1909	669, 827	863	798	3, 034	(1)	59	674, 581
1910	550, 298	45	164	255	(1)	120	550, 882
1911	300, 559	16	800	289	(1)	149	301, 813
1912	546, 071	141	461	895	(1)	139	547, 707
1913	891, 066	447	379	1, 213	(1)	87	893, 192
Hungary, present boundary:							
1921	9, 751	730				89	10, 570
1922	40, 957	9, 643			19, 820	182	70, 602
1923	22, 904	511			27, 792	1	51, 208
1924	30, 113	3, 547			11, 373	983	46, 016
1925	81, 350	1			24, 602	3, 547	109, 500
1926	115, 896				41, 635	163	157, 694
1927	59, 701				55, 050	1, 756	116, 507

1906–1913 total exports from Hungary from Magyar Statisztikai Évkön. 1909: 206; 1912: 227; and 1923: 154.
1906–1913 exports from Austria-Hungary from Statis. Auswärtigen Handels des Vertragszollgebrets der Beiden Staaten der Österr-Ungar Monarchie 1906–1913.
1906–1913 exports from Hungary were larger than those from the dual monarchy, so the difference is assumed to be exported to Austria from Hungary.
1921–1926 from Statisztikai Havi Közlemények, October-December, 1921–1926.
1927 Commerce and industry of Hungary in the year 1927 (*3, p. 118*).

[1] Czechoslovakia was part of Austria-Hungary prior to the World War.

The situation in the hog-feeding industry, which was critical in 1926, became alarming in 1927 in view of the shortage of the 1927 corn crop, which necessitated the import of corn toward the end of the year. The cost of feeding hogs in Hungary was relatively higher than in Rumania and even in Yugoslavia, although there was also a corn shortage in the latter country. The competition of Rumania was strengthened by the abolition of the export fee which had hampered the hog industry of that kingdom in former years. The hog industry of Hungary is suffering from the after effects of the prohibition that was placed upon the export of pork and pork products immediately following the World War and the succeeding system of export permits. During this period, lard and bacon from the United States gained possession of the markets of Austria and Czechoslovakia, and since 1924 it has been extremely difficult for Hungary to combat this competition.

INTERNATIONAL TRADE IN SWINE

Austria, particularly Vienna, is the primary market for the surplus hogs produced in Hungary. Czechoslovakia, on account of the ham and bacon factories in Prague, ranks second. The Austrian and Czechoslovak duty tariffs are so made as to favor the imports of live swine and to hinder the import of bacon, lard, and other pork products. The export of hogs declined sharply in 1927, decreasing to 116,507 as compared with the postwar maximum of 157,694 in 1926. Of the hogs exported in 1927, 59,701 went to Austria, 55,050 to Czechoslovakia, 109 to Yugoslavia, and 104 to Rumania. In addition to hogs, 1,543 pigs weighing up to 30 kilograms (66 pounds) apiece were shipped to Austria and other countries. This decline in hog exports is important to Hungary because Rumanian, Polish, and Yugoslavian competitors have gained ground in the northwestern markets.

Hungary imported 691 hogs from Germany and Yugoslavia, which were to be employed, for the most part, as breeding animals.

FATS AND BACON

Hungary felt the competition of the United States in fats and bacon very keenly during 1926 and could successfully compete only on those markets where consumers were prejudiced in favor of the Hungarian products and were willing to pay higher prices than those asked for the American products.

The export of smoked bacon was restricted because many localities that had purchased Hungarian bacon in former years had equipped themselves during the World War for curing their own pork. The export of lard was facilitated during the year by making up packages of 25 kilograms (55 pounds) each. This is reported to have made selling in foreign markets easier.

The total export of pork and pork products in 1927 fell to 20,147,000 pounds, as compared with 38,131,000 pounds in 1926. This situation is all the more unsatisfactory because Hungarian lard had enjoyed an excellent reputation for many decades.

Lard exports to various countries in 1927 were as follows: To Czechoslovakia, 7,122,000 pounds as compared with 16,370,000 pounds in 1926; to Austria, 2,019,000 pounds as compared with 5,488,000 pounds; to Germany, 538,000 pounds as compared with 757,000 pounds; and to other countries, 253,000 pounds as compared with 29,000 pounds.

The following exports of salt fat sides were made to various countries: Czechoslovakia, 6,550,000 pounds in 1927 as compared with 9,967,000 pounds in 1926; Germany, 563,000 pounds as compared with 2,437,000 pounds; Poland, 1,029,000 pounds as compared with 348,000 pounds; Austria, 151,000 pounds in 1927 as compared with 511,000 pounds to Austria, Italy, and France in 1926.

There were 345,000 pounds of smoked bacon shipped to Austria and Czechoslovakia in 1927 as compared with 305,000 pounds in 1926; 5,000 pounds to Germany, as compared with 24,000 pounds in 1926; whereas other countries took 11,000 pounds in 1927 as compared with 4,000 pounds shipped in 1926.

Hungary exported 1,561,000 pounds of salame sausage in 1927, as compared with 1,891,000 pounds in 1926. Austria absorbed 1,268,000 pounds of the 1927 export.

CATTLE

As in most European countries, the mainstay in farm power in Hungary is the ox; but with the view of building up a dual-purpose industry, milk production as well as work, cattle were introduced from Switzerland and other countries of western Europe. These breeds had, by 1913, crowded most of the native gray steppe cattle back across the Danube and were found in large numbers in the eastern part of the Alföld.

This improvement in the cattle had a stimulating influence upon horse breeding. There are perhaps no better draft oxen in the world than the rangy gray steppe cattle; the steers of dairy breeds are not so well adapted to the plow. Consequently almost everywhere in Hungary it has been necessary to augment the traction power of a yoke of oxen of these dairy breeds by hitching a horse to the plow or load when any particularly heavy work was in hand. As in north Bulgaria, so also in western Hungary, the use of cattle in farm work has given place more and more to horses.

The silver-gray cattle of Hungary are descended from the steppe cattle of Asia and Russia and so are particularly well adapted to the extreme heat and droughts of summer and the rigors of the severe winters experienced upon the great Hungarian plain. These animals are closely related to the Podolian gray cattle of Rumania and southern Russia and probably account for part of the ancestry of the gray cattle of Yugoslavia. They are large boned and rangy, heavy in the forequarters and slight behind, being particularly well adapted to work at the plow under severest conditions, and as J. V. Pirkner (*12*) states: "After 8 to 10 years of uninterrupted labor they can always be fattened for slaughter."

The gray steppe cattle give little milk; their primary function is that of traction animals. For this reason, among the Rumanian and Serbian populations of the old Kingdom of Hungary, cows were yoked into the teams with oxen so that in 1911 fully 530,000 cows were classed as work animals. The Magyar peasants, on the other hand, seldom work their cows in the field, chiefly because they had substituted dairy breeds of cattle for the single-purpose steppe animals, which for 30 years before the World War had occupied a diminishing place of importance among Hungarian herds. In 1884, fully 80.2 per cent of all cattle in the old Kingdom of Hungary were gray Hungarian, Podolian, or similar primitive breeds. In 1895 the percentage had decreased to 65.9; in 1905, to 51.6 per cent; and in 1911, to 31.1 per cent. In 1926, there were only 16.6 per cent of these cattle to be found among the herds of Hungary.

The place of the gray steppe cattle is being taken by the red-mottled dairy cattle of Triburg and the brown Simmenthals and gray Swiss from Switzerland and western Austria.

The numbers of cattle in Hungary had fallen 60,000 below the pre-war average, by 1920. (Table 49.) For the next three years, cattle continued to decrease, reaching the low point of 1,819,000 in 1923 as compared with 2,001,000 before the World War. During the following two years, cattle numbers increased to 1,920,000 or nearly to the 1920 level, but by 1927 fell to 1,805,000, the lowest point since the World War.

TABLE 49.—*Cattle, including water buffaloes: Numbers in the old Kingdom of Hungary for specified years and in Hungary, present boundary, 1911 and 1920–1928*

Territory	Year	Total cattle	Per 1,000 acres [1]	Per 1,000 inhabitants [2]
		Thousands	*Number*	*Number*
Old Kingdom of Hungary, excluding Croatia and Slavonia	1870	3,569	51.1	262.8
	1884	4,879	69.8	339.7
	1895	5,830	83.4	365.7
	1911	6,184	88.5	336.2
Hungary, present boundary	1911	2,001	87.1	261.2
	1920	1,941	84.5	243.2
	1921	1,884	82.0	233.6
	1922	1,828	79.5	224.5
	1923	1,819	79.1	221.3
	1924	1,896	82.5	229.1
	1925	1,920	83.5	229.4
	1926	1,847	80.4	218.7
	1927	1,805	78.5	211.9
	1928	1,812	78.8	210.8

1870–1911 from Magyar Statisztikai Évkön. 1872: 120; 1900: 100; and 1913: 96
1911 new boundaries calculated from same source 1912: 131, 137.
1920 furnished by the Royal Hungarian Ministry of Agriculture.
1921 estimated by interpolating the decrease between 1920 and 1922.
1922–1926 from Magyar Statisztikai Szemle, May–June 1925, January 1926–27
1927 from Internatl. Crop Rpt. and Agr. Statis. (n. s.) 18: 614.
1928 from report of Vice Consul J. H. Morgan, October 21, 1928, Budapest.

[1] For areas pre-war and post-war see footnote 1, Table 45.
[2] For populations 1870–1928 see Tables 8 and 45.

INTERNATIONAL TRADE IN CATTLE

During the 5-year period ended 1913, the old Kingdom of Hungary, including Croatia and Slavonia, shipped to Austria (that is, to the Vienna market) an annual average of 186,760 mature cattle or 68.7 per cent of the beef animals slaughtered in the capital of the former Empire. In addition, 531,182 mature cattle and 211,946 young stock were slaughtered at Budapest and at country centers. This indicates an annual commercial turnover of 929,888 cattle.

An annual average of 634,782 pounds of beef slaughtered in Hungary was shipped to Vienna each year. During this period, Hungary sent to Vienna 24,083 calves and 40,331 pounds of veal. The number of calves slaughtered in Budapest and country centers averaged 574,916 heads each year. An average of 1,553 calves were shipped yearly from Vienna to Hungarian points.

The cattle trade of Hungary can not be compared with that of the old Kingdom during pre-war days. The only point of similarity is that most of the export goes to Austria.

Hungary exported 73,835 cattle of all classes, in 1927, as compared with 91,074 in 1926. Cattle production, as reflected by these international-trade figures, is in the most critical position of any branch of the animal industry. Recovery of cattle numbers in Hungary is retarded by several factors: (1) Reparations payments; (2) the high price of fodder and the high cost of fodder production; (3) more careful selection of individual animals, particularly dairy cows; (4) replacement of oxen by horses in farm work; (5) weakened purchasing capacity of customer countries; and (6) decreased domestic consumption of and, consequently, decreased demand for beef. All these factors have tended to retard production and to decrease the numbers of cattle available for export.

In 1927 Austria was the chief purchaser of Hungarian cattle, absorbing 49,913. Italy took 13,549; Switzerland, 7,975; Czechoslovakia, 2,306; whereas other specified countries took 50 head and the destination of 42 head was not specified.

Hungary imported 1,003 cattle in 1926, of which 165 were purebred stock, chiefly from Switzerland and Holland. The 1927 imports of 2,302 head were not classified.

BEEF PRODUCTION

The number of cattle driven into the Budapest cattle market was reported to be 50,687 in 1927, as compared with 54,810 in 1926. Average weights, except in the case of water buffaloes, were greater than during the previous year. Pasturage is too restricted and the cost of fodder too high in Hungary to render it feasible to raise cattle without obtaining an income from milk or work in addition to the meat produced.

A relatively small number of animals are fattened at distilleries, the breweries, and at sugar factories. Some of the peasants and large landowners stall-feed a few animals each year; but the majority of cows and steers are marketed in whatever condition they happen to be in when they are discarded from the plow or the dairy.

There is no breed of cattle in Hungary specifically adapted to meat production. In the first place, there is little demand for prime beef in the American sense. The peasantry eat very little beef, and the standard of living in the cities is much lower than in western Europe. Steaks are seldom if ever used in the native households. Beef is ground up and mixed with bread crumbs and fried in little pattes called coutlettes, or it is cut up into small morsels and stewed with vegetables in the highly seasoned concoction called goulash. More rarely it is roasted. Fried or broiled beef is restricted usually to the fillet, which is removed from the carcass and sold separately. The greater portion of the beef animal is classed as soup meat, which is boiled both with and without vegetables.

DAIRYING

The old Kingdom of Hungary exported to the former Empire of Austria an average of 147,176,000 pounds of milk, 6,633,000 pounds of butter, and 4,635,000 pounds of cheese during the 5-year period 1909–1913. The greater part of these products was shipped from the western comitats of present Hungary between the Danube River and the Austrian frontier, where the cattle are almost exclusively of the Swiss dairy type.

There were 541 dairy associations that reported in 1909 in the old Kingdom of Hungary. Of this number, 328 societies, located in the districts west of the Danube River, reported 54,398 cows, from which 104,991,800 pounds of milk were delivered to the plants. The associations manufactured 3,450,199 pounds of butter. There is no record of the quantities of milk used at home or of transactions in liquid milk.

There were 72 societies that reported 12,247 cows producing 16,589,000 pounds of commercial milk and 688,000 pounds of butter in the Seven Mountain region, which is now part of the administrative district of Transylvania, in greater Rumania.

At the time of the census enumeration in 1911, there were 921,000 cows in the comitats now comprising Hungary. Doctor Leopold (*9, p. 211*), in commenting on the situation in 1926, placed the number of cows at 900,000. Since the World War, special attention has been given to improving the quality of the cows held on Hungarian farms. Between November 1, 1925, and October 31, 1926, a controlled test of production was made with 420 cows in different parts of Hungary. The cows under test weighed from 1,069 to 1,437 pounds each. The average lactation period was 308 days. The highest group, comprising 39 cows, averaged 9,354 pounds of milk, equivalent to 344 pounds of butterfat, each. The lowest group comprised 62 cows and averaged 7,145 pounds of milk, equivalent to 258 pounds of butterfat. One of the animals tested was the famous Augusta 26, with a record of 28,014 pounds of milk, equivalent to 1,692 pounds of butterfat.

Budapest is the leading market for liquid milk and other dairy products. The daily officially inspected milk supply of Budapest in 1925 was 551,000 pounds, of which 30 per cent was supplied by small peasant farms and 70 per cent by large-estate owners. It is estimated that fully 110,000 pounds of milk produced by uninspected cows is sold illegally in Budapest each day. In 1926, Budapest milk consumption officially had increased to 251,404,000 pounds, or 689,000 pounds each day.

The milk situation in 1927 was characterized by an overproduction which appeared suddenly, increasing the milk supply 30 to 40 per cent above that of 1926, with no compensating increase in the possibilities of sales. Throughout the year the Budapest dairies worked with a surplus varying from 68,000 to 227,000 pounds per day above that which they had been accustomed to handle. There was a small increase in consumption of milk in Budapest during the year. The officially reported sales for 1927 have been placed at 268,191,000 pounds, or 735,000 pounds per day, an increase of 2 per cent over the sales reported the previous year (*15*). It is estimated that the average consumption of milk rose to 0.3 quart per person per day and that home consumption of butter and cheese also showed a tendency to increase. The turnover tax, which burdened the milk industry, was abolished on August 8, 1927, and the price of milk was cheapened, and consumption was, accordingly, stimulated. Nevertheless, there were 551,000 pounds of butter and 1,300,000 to 1,500,000 pounds of curds in cold storage in Budapest at the end of the year. In the opinion of experts, the tendency is toward increased production (*3*).

Development of the dairy industry in Hungary depends upon the feeding-stuff supply which is precarious under the climatic conditions of the great plain (Alföld). Great improvement could be made though better selection of high-producing cows. It is probable that the reduction in numbers of cattle (Table 49) has been partially compensated for by the higher quality of the animals retained.

INTERNATIONAL TRADE IN DAIRY PRODUCTS

In 1926, Hungary exported 6,946,033 pounds of liquid milk, as compared with 10,387,634 pounds in 1925. The 1926 export went chiefly to Austria (6,900,339 pounds), and 38,580 pounds went to Czechoslovakia. Imports, in 1926, were 2,474,223 pounds, as compared with 2,376,559 the previous year. Of this quantity, 2,438,729 pounds came from Czechoslovakia in 1926, as compared with 2,235,244 pounds in 1925.

Hungary exported 441,000 pounds of butter in 1927, as compared with 71,000 pounds in 1926 and 233,000 pounds in 1925. In the summer of 1927 a small amount of butter was imported, probably because of lack of uniformity in production and storage. In 1926, imports of butter, chiefly from Denmark, reached 463,000 pounds, as compared with 437,000 in 1925.

There was no appreciable import of cheese in 1927, and no export. In 1926, Hungary exported 9,000 pounds of hard cheese and 411,000 pounds of soft cheese, for the most part to Austria. The imports of hard cheese (560,000 pounds) and 275,000 pounds of soft cheese were chiefly from Switzerland.

HORSES

The breeding and handling of horses among the Magyars was the special prerogative of the head of the household, whereas, the care of cattle, swine, and sheep among the peasants was left more to the women, old men, and children. The reason for this was that the horse was part of the fighting equipment of the Magyar warrior, and he was responsible to his chieftan for its condition and breed characteristics of speed and endurance. The support of the family devolved upon the nonwarriors. Although somewhat modified by the passing of time, the custom has still persisted in many localities.

The foundation stock of the Hungarian horse-breeding industry is the same small Asiatic breed, scarcely larger than a pony, that carried the hordes of Attila across Russia and swept westward across central Europe to the Rhine in an unbelievably short time. These staunch animals that, as stated by Johann V. Pirkner, "besides the rider often bore a fat ram or even a nobler, two-legged booty thrown across the saddle" are the basis for the world-famous Hungarian horses of modern times. The characteristics of both horse and peasant in Hungary have clung tenaciously to the past. The horses are resistant to extremes of heat and cold and to hard usage. The peasants are unusually loyal to their leaders and have cooperated with the State in improving their horses. In addition to the native Hungarian breed of horse, which varies somewhat with the locality, excellent examples of all the best European and Arabian breeds, are found in Government stables and on large estates.[38]

[38] In 1911 the Government breeding stables reported 187 English thoroughbreds, 1,502 English half bloods 41 Arabian full bloods, 298 Arabian half bloods, 614 Nonius, 203 Gidran, 176 Lipizza, and 142 Norik.

TABLE 50.—*Horses: Numbers in the old Kingdom of Hungary for specified years, and in Hungary, present boundary, 1911 and 1920–1928*

Territory	Year	Horses	Per 1,000 acres [1]	Per 1,000 inhabitants [2]
		Thousands	*Number*	*Number*
Old Kingdom of Hungary, excluding Crotia and Slavonia	1870	1,631	23.3	120.1
	1884	1,749	25.0	121.8
	1895	1,997	28.6	125.3
	1911	1,974	28.2	107.3
Hungary, present boundary	1911	876	38.1	114.4
	1920	685	29.8	85.8
	1921	701	30.5	86.9
	1922	717	31.2	88.1
	1923	815	35.5	99.1
	1924	850	37.0	102.7
	1925	876	38.1	104.7
	1926	885	38.5	104.8
	1927	903	39.3	106.0
	1928	918	39.9	106.8

1870–1911 from Magyar Statisztikai Évkön. 1872: 120; 1900: 100; and 1913: 96.
1911 new boundaries calculated from same source 1912 p. 131 and 137.
1920 furnished by the Royal Hungarian Ministry of Agriculture.
1921 estimated by interpolating the increase between 1920 and 1922.
1922–1926 from Magyar Statisztikai Szemle May–June, 1925, January, 1926–27.
1927 from Internatl. Crop Rpt. and Agr. Statis. (n. s.) 18: 614.
1928 from report of Vice Consul J. H. Morgan, Oct. 24, 1928, Budapest.

[1] For areas see footnote 1, Table 45.
[2] For populations 1870–1928 see Tables 8 and 45.

Hungarian horses are almost universally of the warm-blooded breeds and although well suited to cavalry and other military purposes are nevertheless adapted to light farm work. In Hungary, as in Rumania, Yugoslavia, and Bulgaria, the primary source of farm power is the ox. In recent years, the quality of the oxen has been decreasing, and everywhere horses have been hitched to the plow to supplement the ox team. Although the average weight of horses in Hungary is light, they are being used more and more for farm work. There is need of a heavier draft horse in Hungary and the attention of breeders is being turned in this direction.

In 1911 there were 876,000 horses in the Comitats now comprising Hungary. (Table 50.) The inroads made on Hungarian livestock during the World War decimated the numbers of horses in the country. In 1920 there were 191,000 fewer horses than before the war. During the Rumanian invasion many horses were sequestered permanently. Since 1920 considerable numbers of horses have been sent to Yugoslavia and Czechoslovakia in payment of reparations. In spite of these drafts upon the nation's resources, the numbers of horses on Hungarian farms have increased to such an extent that by 1925 they had reached the 1911 estimated number, and in 1928 were 42,000 above that estimate.

INTERNATIONAL TRADE IN HORSES

During 1927, Hungary exported 1,011 colts, as compared with 765 in 1926, most of which went to Austria. The number of horses more than 2 years old shipped to Austria, in 1927, was 15,315, as compared with 18,330 in 1926. Shipments to various other countries were as follows: To Czechoslovakia, 4,034 in 1927, as compared with 4,208 in 1926; to Italy, 3,760, as compared with 4,981 in 1926; to Switzerland, 1,384, as compared with 691 in 1926; to Rumania, 868, as compared with 464; to Turkey, 486, as compared with 204 in 1926; to Yugoslavia, 54, as compared with 64 in 1926; to Union of Socialistic Soviet

Republics, 2,947; and to other countries 51 in 1927, as compared with 109 in 1926.

Horse breeding and the export of horses are capable of development, and the data of Table 50 indicate that this branch of the animal industry of Hungary is receiving closer attention than is any other.

SHEEP AND GOATS

As in other European countries, the sheep industry of the old Kingdom of Hungary had been on the decline since 1870. The low point was reached in 1895. After that year, there was a slight recovery. The census of 1911 showed 7,698,000, of which number, 2,354,000 sheep were found in the Comitats comprising residual Hungary.

The most usual breed of sheep in Hungary is the Spanish merino, introduced by Queen María Theresia and Kaiser Joseph II. There were 1,546,000 merinos or crosses containing merino blood in 1911 in the Comitats constituting residual Hungary or about 65.7 per cent of total number.

The native milk sheep bearing long, coarse wool numbered 521,000 or 22.1 per cent of total number, before the World War. The most common of these long-wool sheep was the Raczka breed, which was brought by the Magyars from the north Ural regions in Asia, and which exhibit characteristics that are the result of thousands of years of breeding without intermixture from other breeds. Another long-wool, milk sheep is the Czigaja that probably found its way to the Hungarian plains from Rumania and South Russia, but this or a similar breed may have been in possession of the Celtic aborigines before the arrival of the Magyars.

English and other mutton types made up the remaining 12.2 per cent.

In 1920 there were only 1,339,000 sheep in Hungary. There had been an appreciable increase in the number of sheep between 1920 and 1925, in which year 1,891,000 were reported. The next year, 1926, there was a decrease in the number, which continued through 1927 to the spring of 1928, when 1,566,000 sheep were reported on Hungarian farms. (Table 51.)

TABLE 51.—*Sheep: Number in the old Kingdom of Hungary for specified years and in Hungary, present boundary, 1911 and 1920–1928*

Territory	Year	Total sheep	Per 1,000 acres [1]	Per 1,000 inhabitants [2]
		Thousands	*Number*	*Number*
Old Kingdom of Hungary, excluding Croatia and Slavonia	1870	11,920	170.5	877.8
	1884	10,595	151.6	737.7
	1895	7,527	107.7	472.2
	1911	7,698	110.1	418.5
Hungary, present boundary	1911	2,354	102.4	307.3
	1920	1,339	58.3	167.8
	1921	1,346	58.6	166.9
	1922	1,352	58.8	166.1
	1923	1,587	69.1	193.0
	1924	1,811	78.9	219.2
	1925	1,891	82.3	226.0
	1926	1,804	78.5	213.6
	1927	1,611	70.1	189.1
	1928	1,566	68.1	182.2

1870-1911 from Magyar Statisztikai Évkön. 1872: 120; 1900: 100; 1913: 96.
1911 new boundaries calculated from same source 1912: 131, 137.
1920 furnished by the Royal Hungarian Ministry of Agriculture.
1921 estimated by interpolating the increase between 1920 and 1922.
1922-1926 from Magyar Statisztikai Szemle, May-June, 1925, January, 1926-27.
1927 from Internatl. Crop Rpt. and Agr. Statis. (n. s.) 18: 611.
1928 from report of Vice Consul, J. H. Morgan, Oct., 1928, Budapest.

[1] For areas see footnote 1, Table 45. [2] For populations, 1870-1928, see Tables 8 and 45.

There were 34,964 goats in Hungary before the World War. During the unsettled conditions following the war numbers tended to increase, until in 1925 there were 59,831 goats in the country. With improvement in conditions goat numbers have tended to decrease and in 1928 had reached the low point of 29,836. (Table 52.) It is probable that goats (as well as mules and donkeys) will not be important factors in the agriculture of Hungary.

TABLE 52.—*Goats, mules, and donkeys: Number in present Hungary, 1911 and 1922–1928*

Year	Goats	Mules	Donkeys
	Number	*Number*	*Number*
Pre-war year: 1911	34,964	413	7,879
Post-war years:[1]			
1922	48,241	2,232	5,386
1923	45,016	1,991	5,013
1924	55,400	1,963	4,907
1925	59,831	1,787	5,039
1926	48,633	1,747	4,954
1927	36,418	1,657	4,784
1928	29,836	(2)	(2)

1911, calculated from Magyar Statisztikai Évkön. 1912: 126, 137.
1922–1926 from Magyar Statisztikai Szemle, May–June, 1925, January, 1926, and January, 1927.
1927 from Internatl. Crop Rpt. and Agr. Statis. (n. s.) 18: 614.
1928 from report of Vice Consul J. H. Morgan, Oct. 24, 1928, Budapest.

[1] 1920 and 1921 not available. [2] Not available.

INTERNATIONAL TRADE IN SHEEP AND GOATS

The export of sheep, lambs, and goats from Hungary dropped from 46,741 in 1925 to 38,918 in 1926 and to 24,570 in 1927. The decline in exports was the result of weakened demand in customer countries and to increased competition in the markets of central and western Europe. Switzerland took 13,349 sheep in 1927 as compared with 24,463 in 1926. Exports to various other countries were as follows: To Czechoslovakia, 6,502 in 1927, as compared with 8,370 in 1926; to Austria, 3,384 as compared with 4,051; to France, 1,292 as compared with 1,931; to other countries 43 in 1927, as compared with 103 sheep in 1926.

A small amount, 467,000 pounds of fresh mutton, lamb, and goat meat was exported in 1927 as compared with 498,000 pounds in 1926.

WOOL

Under the Austro-Hungarian Monarchy the textile industry was little developed in the Comitats now comprising Hungary. Most of the commercial wool produced was shipped to the mills in Bohemia, Moravia, and Silesia, or to Germay and other countries. Since the treaty of Trianon, the Hungarian woolen industry has recovered very slowly. In 1922 the production of domestic mills covered about 10 per cent of the requirement; in 1923, about 25 per cent; and, in 1924, about 40 per cent. In 1924, there were 25,000 spindles and 1,100 looms in operation.

In 1926 the wool clip was estimated at 16,534,500 to 17,636,800 pounds, most of which was shipped abroad. The total export was 13,934,174 pounds, or about 8.5 per cent less than the 15,234,006 pounds exported in 1925. Of this export, 6,233,727 pounds went to

Germany, 5,002,899 pounds went to Czechoslovakia, and 1,017,643 pounds went to Italy.

The production of wool, in 1927 was about the same in quantity as in the previous year, but the quality was, according to test washings, 1 to 2 per cent better.[39] In recent years the smaller farmers have devoted greater care to sheep breeding and have taken better care of the wool than before the World War.

The home industry in 1927 bought 6,600,000 pounds, and the remainder, for the most part, was exported. The various leading countries to which wool was exported and the quantities taken were as follows: To Germany, 5,054,000 pounds; to Czechoslovakia, 2,791,000 pounds; to Rumania, 736,000 pounds; to Austria, 575,000 pounds; to Poland, 485,000 pounds; to Belgium, 323,000 pounds.

Hungary imported 4,511,000 pounds of wool in 1927, as compared with 2,325,633 pounds in 1926.

At the present time, Hungarian wool is not known on the European market. There are no associations to bring the farmers and the export buyers together. According to United States Commercial Attaché W. A. Hodgman, about 75 per cent of German wool, 90 per cent of Australian, and 90 per cent of South American wool is of first quality. Only a very small proportion of Hungarian wool comes up to the quality produced in these countries. The Hungarian farmer knows nothing about modern preparation of wool for marketing and usually packs the wool without airing, which gives the product a yellow color.

MEAT PRODUCTION AND CONSUMPTION

No data are available relative to home slaughterings in Hungary before or since the World War, but the numbers of animals reported to have been slaughtered in officially recognized slaughterhouses in the former Kindgom had been gradually increasing with the exception of sheep and goats from 1893 until 1913.

During the 20-year period ended 1913, there had been a continuously steady increase in the numbers of cattle and swine slaughtered for each 100 inhabitants. (Table 53.)

Unofficial figures (*15, p. 44–45*) indicate that there has been an increase in meat consumption in Hungary between 1924 and 1926. The numbers of animals killed in slaughterhouses in 1924, showed an increase of 9.9 per cent over 1923. The following year, the increase reached 39.2 per cent and, in 1926, was 59.7 per cent greater than in 1923.

Comparing the data for 1926 with the 1909–1913 average given in Table 53 indicates that the supply of meat from slaughterhouses per 100 inhabitants in Hungary was greater than it was in the old Kingdom, about half of whose inhabitants ate meat not more than 10 times during the year. The treaty of Trianon segregated from Hungary the districts of lowest meat consumption—Slovakia, Ruthenia, Transylvania, Voivodina, Croatia, and Slavonia. It is to be expected that the statistical disappearance of meat in Hungary, including Budapest, would be greater than in the old Kingdom, including the

[39] The wool department of the Hungarian General Credit Bank estimated the 1927 clip at approximately 16,500,000 pounds of wool. MORGAN, J. H., PRODUCTION OF WOOL AND NUMBER OF SHEEP IN HUNGARY. Cons. Rpt. Jan. 11, 1928, 2 p. 1928. [Typewritten copy, on file in Bureau Agricultural Economics Library.]

TABLE 53.—*Animals slaughtered for general consumption in the old Kingdom of Hungary, for specified years*

Year	Public slaughter-houses	Bulls	Steers	Cows	Young cattle	Water Buffaloes	Calves	Sheep	Lambs	Goats	Kids	Swine	Horses
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
Average:													
1893–1895	2, 065	9, 806	172, 443	237, 584	111, 356	6, 826	432, 274	974, 740	649, 094	26, 026	31, 404	758, 244	(1)
1896–1900	2, 105	12, 010	183, 989	296, 767	131, 500	9, 063	465, 391	747, 869	570, 286	24, 109	30, 893	831, 763	(1)
1901–1905	2, 224	16, 191	181, 294	305, 349	169, 250	9, 554	502, 136	717, 848	537, 088	18, 768	15, 855	1, 011, 722	2, 682
1906–1910	2, 174,	26, 078	183, 699	307, 977	195, 025	14, 102	561, 185	758, 404	584, 229	20, 783	18, 293	1, 239, 844	7, 740
1909–1913	2, 244	31, 417	156, 633	343, 132	[2] 211, 946	12, 470	[2] 574, 916	840, 403	593, 840	27, 099	22, 461	1, 473, 866	12, 500
1909	2, 139	32, 950	189, 658	402, 956	[2] 279, 773	27, 562	[2] 743, 687	900, 496	605, 508	24, 762	18, 227	1, 379, 720	8, 149
1910	2, 359	27, 433	174, 207	401, 209	[2] 220, 193	13, 825	[2] 635, 737	834, 050	641, 098	21, 674	23, 884	1, 301, 805	11, 194
1911	2, 341	28, 542	150, 956	307, 220	[2] 164, 796	8, 293	[2] 524, 114	787, 374	572, 803	27, 636	20, 843	1, 312, 974	15, 296
1912	2, 298	32, 161	141, 503	283, 916	[2] 169, 639	6, 463	[2] 554, 189	808, 991	597, 531	31, 714	32, 193	1, 564, 517	14, 551
1913	2, 083	35, 999	126, 841	320, 327	[2] 225, 329	6, 209	[2] 416, 853	871, 104	552, 261	29, 707	17, 159	1, 810, 315	13, 311

PER 100 INHABITANTS

Year	Public slaughter-houses	Bulls	Steers	Cows	Young cattle	Water Buffaloes	Calves	Sheep	Lambs	Goats	Kids	Swine	Horses
Average:													
1893–1895	0. 013	3. 43				0. 04	2. 79	10. 49		0. 37		4. 89	(1)
1896–1900	. 013	3. 82				. 06	2. 85	7. 87		. 34		5. 08	(1)
1901–1905	. 012	3. 87				. 06	2. 89	7. 22		. 20		5. 82	0. 02
1906–1910	. 012	3. 92				. 08	3. 09	7. 39		. 22		6. 82	. 04
1909–1913 [3]	. 012	0. 17	0. 86	1. 88	1. 16	. 07	3. 15	4. 60	3. 25	. 27		8. 07	. 07
1926 [4]	------	. 23	. 47	1. 54	------	------	4. 69	4. 37	------	------		14. 17	. 20

From Magyar Statisztikai Évkön. 1896: 148; 1900: 104; 1912: 140; 1913: 99.

[1] No report.
[2] The young cattle that were slaughtered in Budapest are included with calves.
[3] Population 1910 excluding Croatia and Slavonia=18,264,533.
[4] Die Volkswirtschaft Ungarns im Jahre 1927. (*15, p. 45.*)

outlying districts of low consumption. Nevertheless, if the meat produced by the animals killed in the slaughterhouses of Hungary, in 1926, be compared with that produced by the same slaughterhouses before the World War, an increase of 29.5 per cent is indicated (*15, p. 45*). It appears that more calves, but less mature cattle, are being slaughtered than before the war. The numbers of swine passing through slaughterhouses of Hungary in 1926, was 75.6 per cent greater than the official slaughterings of the old Kingdom before the war. It must be remembered, in this connection, that the pork produced in slaughterhouses represents only a small portion of the pork consumed in the country as a whole. Large numbers of swine, lambs, goats, fowls, and hares are slaughtered at home whereas cattle and horses, without exception, are killed in official slaughterhouses.

It has been noted, in recent years, that householders in Budapest and other large centers show a tendency to keep pigs and fowls at home for family use. The numbers of such animals that are consumed at home do not appear in public records. However, the number of licenses issued to city householders to slaughter swine at home increased from 355, in 1923, to 1,624, in 1926. Many more than this number slaughter without license.

Hungary is undoubtedly eating more pork, fowls, and horse meat than before the war. Less numbers of cattle have been slaughtered but, on the other hand, the weights of cattle slaughtered during the first six months of 1927 averaged greater than during the last six months of 1926. Bulls weighed 1,230 pounds in 1927 as compared with 1,202 pounds in 1926; steers 1,380 pounds as compared with 1,349 pounds; and cows 1,089 pounds in 1927 as compared with 1,056 pounds in 1926. It may be that decreased numbers of cattle slaughtered may in a measure be compensated for by the increased average weight of the animals sent to the block.

SUMMARY

Hungary is an agricultural country in which the manufacturing industries are of secondary importance. Hungary produces exportable surpluses of practically all farm products. In 1927, plowlands reached 60.3 per cent of the total area; meadows and pastures, 18.1 per cent; forests, 11.7 per cent; gardens and vineyards, 3.4 per cent; and 6.5 per cent was in reeds or was unproductive.

The people of Hungary are Magyars—of Asiatic origin similar to the Finns. They are highly intelligent and traditionally patriotic. They are a home-loving folk deeply attached to the soil of their ancestors.

The soil of Hungary is generally a fertile black loam except for sandy stretches, particularly along the eastern banks of the Danube River. The great handicap to agriculture is the precarious climate. Droughts are common during the growing season and short crops must be expected occasionally, as in 1924.

There was a land reform in Hungary as in other succession States, during which 1,590,000 acres changed hands. The scope of this land reform was not as sweeping as in Russia and Rumania, but its effects are perceptible.

Hungary had nearly 500,000 more acres under plow in 1927 than before the World War, at the expense of meadows, pastures, and forests. In 1928 cereal acreage was 104 per cent of the pre-war average; potatoes, 105.8 per cent and sugar beets, 125.2 per cent. On the other hand, cattle were 90.5 per cent of the 1911 census numbers, swine, 82.8 per cent, and sheep 66.6 per cent. Horses alone show several thousand more head than before the World War. It is probable that the locally bred livestock have practically recovered their pre-war status but that this number is considerably less than reported in 1911 because at that time thousands of lean animals shipped in from outlying districts were being fattened in the feed lots about Budapest and in the western counties between Budapest and Vienna.

Hungary is primarily a wheat-producing country, 41 per cent of the cereal acreage being under wheat in 1928. Wheaten bread forms the basis of the peasant diet whereas in Austria, Czechoslovakia, Germany, Poland, and eastern Europe the common bread is rye. Excepting the poor crop season of 1924–25, wheat production in Hungary in recent years has been greater than before the World War. During 1927–28, Hungary exported (net) 21,491,000 bushels of wheat and flour in terms of grain as compared with an estimated average surplus of 20,489,000 bushels during 1909–1913.

Budapest, next after Minneapolis, was the largest milling center in the world before the World War. Since the war, on account of governmental regulation and heavy taxation, the flour-milling industry has been permanently crippled, and some of the large mills have been dismantled. In 1913 the total wheat and wheat-flour exports (in terms of grain) of the entire Kingdom of Hungary amounted to 55,233,000 bushels, 18,433,000 bushels of which were exported as grain and 36,800,000 bushels as flour. In 1927–28 Hungary exported (net) 21,491,000 bushels of wheat, 12,004,000 bushels as grain, and 9,487,000 bushels as flour.

Just before the World War, the acreage of wheat in Hungary had become practically static although production fluctuated with the fluctuating changes in climate. In good seasons the people of Hungary used more wheat, but, also, the merchants and mills exported more wheat than was, on the average, customary. On the other hand, during poor crop seasons a less-than-average quantity of wheat was eaten and exported. Since the World War, Hungary has been exporting the maximum volume of wheat possible and has left within the country only the smallest quantity that would maintain the population. The Government has encouraged the use of rye as a wheat substitute. As a result, the per capita net disappearance of wheat during 1922–23, 1923–24, 1925–26, and 1926–27 appears to have been nearly static, varying only slightly above or below the mean level of 4.98 bushels. This has resulted in a high correlation of 0.999 between per capita net production and per capita net exports.

This indicates that under the conditions that prevailed during these four years there was an average tendency for the per capita net production of any given year to be associated with per capita net export equivalent to 4.92 bushels less than 0.9909 times the production or $E' = 0.9909\ P - 4.92$.

There was 68 per cent tendency for observed per capita net exports to approximate the calculated exports within a range of $\pm\sqrt{\frac{\Sigma(E-E')^2}{n}}$; which, in this case was ± 0.03 and a 99 per cent tendency that under average conditions the range would approximate ± 0.09 bushel per capita.

In 1927, per capita net production of wheat was 7.65 bushels. Under the average conditions that prevailed during the four years 1922–23, 1923–24, 1925–26, and 1926–27, there were 68 chances in 100 that per capita net exports during the season 1927–28 would approximate $(0.9909 \times 7.65) - 4.92$ or 2.66 bushels within a range of ± 0.03 bushel, 95 chances that the range would be ± 0.06 bushel, and 99 chances that the range would be ± 0.09 bushel per capita. That is to say, that in 99 per cent of cases the export could be expected to range from 2.57 to 2.75 bushels per capita, if conditions remained average. The actual net export during the season 1927–28 was 2.52 bushels per capita or 0.05 bushel below the lower limit of range.

The price relationships of wheat in Hungary and in near-by importing countries was not sufficiently wide to exercise an average pull on Hungarian wheat during the crop year 1927–28. On the other hand, rye prices abroad were relatively high and rye moved abroad in spite of a short crop at home, resulting in the greater use of wheat and the lesser use of rye in domestic bread making than was the case the previous season. Domestic disappearance of wheat rose to the post-war maximum of 5.13 bushels per capita.

The producton of rye in Hungary is of third-rate importance, being superseded by wheat and corn. Before the World War, the Comitats now comprising Hungary produced an estimated rye surplus of about 15,826,000 bushels. Since the war, rye acreage has increased; but even excluding the poor crop season of 1924–25,the average production of recent years has been somewhat less than that of pre-war.

Per capita disappearance, however, has averaged about 2.25 bushels during 1922–23, 1923–24, 1925–26, and 1926–27, as compared with 1.4 bushels before the World War. This has resulted in decreased net exports ranging from 2,572,000 bushels in 1922–23 to 10,240,000 bushels in 1926–27. During these four years there was a correlation between per capita net production and per capita net exports of ± 0.74. On the average, the calculated per capita net export of rye associated with the production of any one year was found by the equation $E' = 0.7556P - 1.51$.

There was a 68 per cent tendency for observed per capita net exports to approximate the calculated exports within a range of ± 0.216 bushel, a 95 per cent tendency toward a range of ± 0.432 bushel, and a 99 per cent tendency toward a range of ± 0.648 bushel.

In 1927, per capita net production of rye was 2.04 bushels. The calculated per capita net export that could be expected to be associated with a production of 2.04 bushels would (under the average conditions that prevailed during 1922–23, 1923–24, 1925–26, and 1926–27) be approximately $(0.7556 \times 2.04) - 1.51$ or 0.03 bushel. That is to say, in 99 per cent of cases the crop-year's balance would range from an import of 0.618 bushel to an export of 0.678 bushel per capita.

The actual net export during the crop year 1927–28 was 0.525 bushel per capita or 0.123 bushel below the upper limit of range.

The surplus rye-producing Comitats lie in the northwestern part of Hungary along the Danube, easily accessible to the importers of Austria and Czechoslovakia, but not easily accessible to the merchants of the deficit Comitats of the interior of Hungary. These interior Comitats are near to the southern surplus wheat-producing Comitats. The price differences between rye in Hungary and in the near-by importing countries was greater than average and exerted such a strong pull that, in spite of a rye shortage at home, a very considerable quantity of rye was shipped abroad.

The export situation as regards wheat and rye should be considered from the collective viewpoint of bread cereals rather than from that of either cereal taken separately. Not only is rye employed as a substitute for wheat in Hungarian bread, but merchants show a preference for exporting whichever cereal offers the greatest margin of profit, so that wheat and rye, as export commodities, are, in a sense, interchangeable depending upon the relative price relationships of either cereal in Hungary as compared with the prices offered in importing countries.

The decreases in both acreage and production of barley in Hungary are probably aftereffects of the land reform. The years of highest post-war export show that shipments abroad have been about one-fourth of the estimated pre-war average. It is probable that a growing animal industry will make increasing demands upon domestic production so that barley exports will probably not in future reach their pre-war magnitude of 8,609,000 bushels.

Acreage and production of oats in Hungary seem to be on the decline. The increasing use of automobiles has reduced the city demand. The influence of peasant farming is now greater than formerly on account of the land reform. The peasants of Hungary do not utilize oats to the extent that they are fed in northwestern Europe. More corn is fed on small holdings and therefore, following the land reform, the area seeded to oats will probably tend to remain below the pre-war average.

Horse breeding will probably not expand greatly and domestic utilization will probably tend to remain about 19,000,000 bushels annually. Exports will probably tend to fluctuate with fluctuations in production.

Corn is, next to wheat, the most important field crop in Hungary. The increased preponderance of peasant farming in Hungarian agriculture has tended to stimulate corn production but on account of the precarious climate yields fluctuate widely. (Table 34.) There is a correlation between corn and hog production in Hungary similar to that in the United States and therefore exports fluctuate in response to the influence of domestic and foreign demand upon production. It is probable that disappearance of corn in Hungary will tend to increase in response to the demands of a growing animal industry, but as indicated during the seasons 1924–25 and 1925–26 exports will tend to range far above the pre-war average of 1,196,000 bushels.

The acreage of potatoes takes sixth place among Hungarian field crops and does not occupy such an important position in the farm life of the nation as in Czechoslovakia, Germany, or Poland. Since the World War, acreage has tended to range above, and with the exception of the crop year 1927–28, production below the pre-war levels. Disappearance has also been less with the exception of 1925–26 than before the World War and in recent years exports have been higher than the pre-war average of 893,000 bushels.

Between 1924 and 1928, acreage of sugar beets has been greater and production has averaged about the same as the period 1909–1913. Production of sugar, however, has only once (in 1924–25) reached the pre-war level of 222,306 short tons and exports since 1923–24 have averaged about 90,000 short tons or about one-tenth as much sugar as is shipped annually from Czechoslovakia. The industry of Hungary has been hampered by so-called governmental participation and although exports may increase somewhat they will probably not tend to materially affect the markets of western Europe.

As in all countries in which the tobacco industry is conducted as a Government monopoly, acreage and production of tobacco in Hungary are regulated to return a profit to the State. Both acreage and production in recent years have ranged below the pre-war levels, but the situation is of little interest to American growers as the consumption of American tobacco in Hungary is negligible and Hungarian tobacco does not compete on European markets with that grown in the United States.

Hungary produces no cotton. In 1927, the spinning industry utilized 16,770,000 pounds, more than 75 per cent of which originated in the United States. The industry is slowly developing.

Whereas meadows and pastures and fodder plants have changed but little in acreage in recent years, fodder production in Hungary appears to have increased during the four years ended 1927. The development of the livestock industry depends upon cultivated forage production, because the area of meadows and pastures which are almost universally common village property, is strictly limited. Future improvement in the forage situation will probably follow the lines of better varieties and seed rather than changes in acreage as the area can not be increased to any material extent without decreasing that of cereals, potatoes, or sugar beets.

During the centuries, as life has changed from one of warfare to that of farming, the preferences of Hungarian peasants have shifted from horse breeding as their main occupation to swine and cattle production. In this direction the Hungarians have made great progress so that the number of animals to be grazed on village pastures, the adaption of breeds to given localities, the number of sows bred to a single male, the qualities of males as to breed characteristics, and other questions are under the observation of the rural police. To a great extent, the primitive breeds of cattle, sheep, and swine common to southeastern Europe have been replaced by improved breeds from the northwest and the native strains of horses have been bred up to a standard of excellency of world-wide recognition.

Hungary is a corn-growing country and a potential producer of pork and pork products that may compete with the United States in south central Europe at least. At present, lard from the United States has penetrated into Austria, Czechoslovakia, and western Yugoslavia, all of which countries border on Hungary. Up to 1926, Hungary has not been able to compete with fats and bacon from the United States except on those markets where the consumers were prejudiced in favor of the Hungarian product. But when the political and economic situation has reached greater stability in Europe, Hungary will undoubtedly offer American pork and pork products sharp competition in central Europe. In 1927, Hungary exported 116,507 hogs, 9,900,000 pounds of lard, and 8,700,000 pounds of fat sides and bacon.

Dairying has been rapidly replacing the breeding of cattle for draft purposes in Hungary, since 1926, fully 83.4 per cent of all cattle were of improved stock. There is, in the American acceptation of the term, no beef breed in Hungary. Dairying will probably, at no future time, reach proportions greater than required to cover local needs and to supply a part of Vienna's milk and meat requirement. The quality of meat exported to Austria is very poor according to American standards. In 1927, Hungary exported 74,000 cattle of all classes, and 2,302 were imported.

The foundation stock of Hungarian horse breeding is the small Asiatic breed that carried the Magyar hordes across Russia and part of Europe in an unbelievably short time. These wiry little horses of the light cavalry type are in demand in surrounding countries. Nearly 30,000 colts and horses were exported in 1927.

The most usual sheep of residual Hungary is the Spanish merino, constituting about two-thirds of all herds. About 12 per cent of all sheep are English meat types, whereas about 22 per cent are aboriginal coarse wool, milk sheep. Hungary exported approximately 10,000,000 pounds of wool in 1927 and imported about 4,500,000 pounds.

Hungary is an agricultural country in which industries are relatively little developed. It is not possible to expand the agriculture of this country to any marked degree except by improved breeds of plants and animals and by improved methods.

The aim of the Hungarian peasant is a peaceful existence. He is slow to change his agricultural habits. It is probable that the animal industry will be given a place of greater importance in the future than in the past; but any changes in this direction will be effected gradually. Unless marked improvement is made in production methods, the long-time competition of Hungary with the farmers of the United States will be marked by decreased exports of cereals and increased shipments of animals and animal products up the Danube River.

AVERAGE VALUES OF THE HUNGARIAN CROWN AND PENGÖ

The monthly average values of the Hungarian crown, July, 1921, to December, 1925, and the Hungarian pengö, January, 1926, to December, 1928 are given in Table 54.

TABLE 54.—*Monthly average values of the Hungarian crown, July, 1921, to December, 1925, and of the Hungarian pengö, January, 1926, to December, 1928*

Month	Cents per crown					Cents per pengö		
	1921	1922	1923	1924	1925	1926	1927	1928
January	------	0.15	0.04	0.0039	0.00135	17.55	17.53	17.47
February	------	.15	.04	.0033	.0014	17.56	17.53	17.47
March	------	.13	.03	.0015	.0014	17.56	17.51	17.47
April	------	.13	.02	.0014	.0014	17.56	17.48	17.46
May	------	.13	.02	.0013	.0014	17.56	17.46	17.46
June	------	.11	.01	.0012	.0014	17.56	17.44	17.45
July	0.33	.08	.01	.0012	.0011	17.57	17.44	17.44
August	.26	.06	.01	.0013	.0014	17.56	17.44	17.43
September	.19	.04	.01	.0013	.0014	17.56	17.47	17.43
October	.14	.04	.01	.0013	.0014	17.56	17.46	17.43
November	.11	.04	.01	.0013	.0014	17.56	17.47	17.42
December	.15	.04	.01	.0013	.0014	17.57	17.48	17.42
Average yearly value	------	.09	.016	.00169	.0014	17.56	17.48	17.46

From Federal Reserve Board:
Par value of the gold crown = 20.26 cents.
Par value of the pengö = 17.49 cents.
One pengö = 12,500 paper crowns.

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TECHNICAL BULLETIN No. 159 — OCTOBER, 1929

UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

KEEPING QUALITY OF BUTTER MADE FROM CREAM OF VARIOUS ACIDITIES

By WILLIAM WHITE, *Senior Dairy Manufacturing Specialist*, *and* C. S. TRIMBLE *and* H. L. WILSON, *Associate Dairy Manufacturing Specialists, Division of Dairy Manufacturing Investigations and Introduction, Bureau of Dairy Industry*

CONTENTS

INTRODUCTION

The custom of permitting cream to sour before churning developed centuries ago, partly as a matter of necessity. The cream was separated by gravity, the accumulation of a sufficient volume of cream to make a churning required some time, and difficulty was experienced in keeping the cream cold during warm weather.

Some of the early butter makers, however, perhaps learned from experience that sour cream churned more quickly than sweet cream and produced a little more butter from an equal volume of cream. These results would indicate that the souring of cream was desirable. The flavor and aroma developed by the souring of the cream were present in the butter and came to be considered characteristics of butter.

When the factory system of butter making was introduced, the souring or ripening of cream previous to churning was a custom so well established that the creamery butter maker adopted it as a matter of course. Even after the cream separator came into general use and sweet milk was delivered to the creamery this custom was not changed. Indeed the ripening of the cream was such an important step in butter making that the use of a starter, consisting of a culture of lactic-acid-producing bacteria, became a general practice in order that the development of a desirable acid flavor might be assured.

The undesirable flavors obtained when the cream became too sour, however, were noted many years ago. Henry Ward Beecher (*1*)[1] in 1859, severely criticised the quality of butter found on the mar-

[1] Italic number in parentheses refer to literature cited, p. 7.

70920°—29

ket and recommended that the cream be churned while still sweet. The same idea is presented in the following statement in the second annual report of the New York State dairy commissioner (*2, p. 309*) for 1886:

> The best flavored butter is made from "sweet cream," although cream is often allowed to become slightly sour before churning. If the acid fermentation is allowed to go too far it will deleteriously affect the butter.

In 1889 the West Virginia Experiment Station (*6*) reported that the college creamery had established a good demand for sweet-cream butter. In 1890 and 1892 the Iowa Experiment Station (*7, 8*) reported that sweet-cream butter kept better than sour-cream butter. In both instances the sweet-cream butter was made from raw cream.

In 1902 Leclair (*4*) of the St. Hyacinthe Dairy School, Quebec, Can., recommended pasteurizing sweet cream, cooling it, holding it for three hours, adding 30 per cent lactic culture, and then churning it at once. After adopting this practicing he obtained fine-quality butter that was very uniform from day to day. He did not, however, report its keeping quality in storage.

A study, begun in 1905 by the United States Department of Agriculture (*3, 9, 10, 11*), of the influence of acidity of cream on the keeping quality of butter established the fact that butter made from unripened, pasteurized sweet cream maintained its fine quality to a high degree during at least eight months' storage at 0° F.[2] Mortensen (*5*), in 1922, concluded from his work that ripened-cream butter received a higher commercial score when fresh but that sweet-cream butter kept better in storage.

As a result of the work already accomplished, creamery operators have adopted the practice of churning cream at lower acidities than was their custom in the past. The degree of acidity at different creameries, however, still varies materially.

EXPERIMENTAL

LABORATORY BUTTER

Four series of churnings were made for the purpose of obtaining data on the maximum acidity that cream may contain without hastening deterioration of the butter. In these series the cream ranged in acidity from 0.11 to 0.45 per cent, calculated as lactic acid. The keeping quality of the butter [3] obtained is reported.

The cream was usually standardized to 30 per cent butterfat, but when this was not done the acidity of the serum was calculated to that basis. For standardizing the acidity to the desired points a lactic culture in skim milk was used for acidities up to 0.25 per cent and in some cases up to 0.31 per cent. To obtain higher acidities the cream was ripened, a lactic culture being used for a starter. The cream was pasteurized in shotgun cans or in a steam jacketed vat, run over a cooler, held overnight, and churned the next day in a small combined churn and worker, 8 to 10 pounds of butter being made in each churning. The butter in all churnings was washed, salted, and worked in the same manner; and all conditions were controlled as

[2] Because of this work the U. S. Navy in 1909 adopted the practice of purchasing each year a quantity of sweet-cream butter to be placed in cold storage and used throughout the ensuing year. This practice is still continued.

[3] The word "butter" in this bulletin refers only to salted butter.

closely as possible. The composition of most of the butter came within the following range: Butterfat, 80.8 to 83 per cent; moisture, 14 to 15.8 per cent; salt, 1.8 to 2.8 per cent; curd and ash, 0.7 to 1 per cent. The butter was solidly packed into 2-pound paraffined fibre containers.

Samples of each churning were stored in two refrigerators, one of which was maintained most of the time at a temperature of approximately 0° F. though the range was from −5° to 20°. The latter temperature, however, occurred only a few times and for short periods except at the time that series 4 was in storage, when a temperature of 20° was reached daily for two weeks. The temperature of the other refrigerator ranged from 30° to 50°. This refrigerator was used for various purposes, and the door was frequently opened during the day.

The butter was scored by competent butter graders, one from the Bureau of Agricultural Economics[4] and two from the Bureau of Dairy Industry. None of the men knew the identity of the samples being scored.

SERIES 1

Ten lots of sweet cream were each divided into five parts, one of which was used sweet, the acidity of the cream averaging 0.15 per cent; and the others were standardized to 0.22, 0.25, 0.28, and 0.31 per cent acid respectively. The cream was pasteurized after the acidity had been standardized. The organisms and flavor of the lactic culture, therefore, were largely destroyed. The butter was made during the winter when the cows were on dry feed. Table 1 shows the average scores of butter when fresh and after different periods of storage.

TABLE 1.—*Average scores of butter when fresh and after different periods of storage*

[Ten churnings at each acidity]

Cream acidity when churned	Fresh	After 4 months at 30° to 50° F.		After 8 months at 0° F.		After 8 months at 0° F. and 2 months at 30° to 50°		After 12 months at 0° F.	
	Score	Score	Decrease	Score	Decrease	Score	Decrease	Score	Decrease
Per cent	*Points*	*Points*	*Points*	*Points*	*Points*	*Points*	*Points*	*Points*	*Points*
0.15	90.49	89.78	0.71	90.13	0.36	89.20	1.29	89.32	1.17
.22	90.67	89.70	.97	90.21	.46	89.35	1.32	89.17	1.50
.25	90.57	89.62	.95	90.22	.35	89.10	1.47	89.29	1.28
.28	90.46	89.47	.99	90.12	.34	88.15	2.31	88.71	1.75
.31	90.32	89.19	1.13	90.10	.22	87.90	2.42	88.51	1.81

When stored for eight months at 0° F. all of this butter kept equally well and deteriorated very little. After the longer storage periods butter in the 0.28 and 0.31 per cent acid groups had deteriorated more than that in the lower acidity groups. After four months' storage at 30° to 50° butter in the 0.31 per cent acid group had lost 0.42 point in score more than that in the 0.15 per cent acid group.

[4] The authors wish to express their appreciation of the work of C. E. Eckles, Bureau of Agricultural Economics, U. S. Department of Agriculture, in scoring the many samples of butter used in this investigation.

SERIES 2

In series 2 the procedure was similar to that of series 1, except that the acidity was standardized after pasteurization. The organisms and flavor of the lactic culture, therefore, remained. This butter was also made during the winter. Seven churnings of each acidity were used in this series. The scores are shown in Table 2.

TABLE 2.—*Average scores of butter when fresh and after different periods of storage*

[Seven churnings at each acidity]

Cream acidity when churned	Fresh	After 4 months at 30° to 50° F.		After 8 months at 0° F.		After 12 months at 0° F.		After 12 months at 0° F. and 3 weeks at 30° to 50°	
	Score	Score	Decrease	Score	Decrease	Score	Decrease	Score	Decrease
Per cent	*Points*	*Points*	*Points*	*Points*	*Points*	*Points*	*Points*	*Points*	*Points*
0.15	91.10	89.21	1.89	90.55	0.55	89.67	1.43	89.50	1.60
.22	91.02	88.93	2.09	90.58	.44	89.58	1.44	88.92	2.10
.25	91.29	88.86	2.43	90.69	.60	89.83	1.46	89.08	2.21
.28	91.38	88.89	2.49	90.65	.73	89.25	2.13	88.67	2.71
.31	91.14	88.71	2.43	90.38	.76	88.58	2.56	87.92	3.22

When stored for 8 months at 0° F. all the butter had good keeping quality. After 12 months at 0° butter in the 0.28 and 0.31 per cent acid groups had deteriorated more than that in the lower acid groups; and after an additional 3 weeks at 30° to 50° there was a progressive increase in deterioration from 1.60 points for the 0.15 per cent acid group to 3.22 points for the 0.31 per cent acid group. After 4 months at 30° to 50° butter in the 0.25, 0.28, and 0.31 per cent acid groups had lost about one-half point in score more than that in the 0.15 per cent acid group.

SERIES 3

In series 3 a comparison was made of the quality of butter while fresh and after different periods of storage when cream was treated in different ways but churned at the same acidity. These churnings were made during the summer when cows were on pasture.

Nine lots of sweet cream were each divided into four parts, each part receiving a different treatment as follows: (1) Cream pasteurized sweet, then culture added just before churning to increase the acidity to 0.25 per cent; (2) culture added to cream to increase the acidity to 0.25 per cent, then pasteurized; (3) raw cream ripened with a culture to 0.35 per cent acidity, then neutralized with lime to 0.25 per cent and pasteurized; (4) raw cream ripened with a culture to 0.45 per cent acidity, then neutralized with lime to 0.25 per cent and pasteurized. The scores of this butter are shown in Table 3.

TABLE 3.—*Scores of butter when fresh and after storage for four months at 30° to 50° F. and eight months at 0°*

[Nine churnings of each method]

Cream No.	Fresh	After 4 months at 30° to 50° F.	After 8 months at 0° F.	Cream No.	Fresh	After 4 months at 30° to 50° F.	After 8 months at 0° F.
1	92.56	88.70	90.85	3	91.86	88.66	90.96
2	92.17	88.90	90.82	4	91.83	88.95	91.02

The scores of the fresh butter varied materially on account of the different methods of treating the cream. No. 1 had a good culture aroma and flavor; Nos. 3 and 4 had a slightly coarse flavor. After storage at 30° to 50° F. for four months all butter was of about the same quality. This was also the case after eight months at 0°. Developing acid in cream Nos. 3 and 4 with a lactic culture and reducing it with an alkali injured the flavor of the fresh butter slightly but did not lower its keeping quality. The acidity of the cream when churned rather than the acidity previous to treatment is the factor affecting keeping quality of butter.

SERIES 4

In this series seven churnings of cream were pasteurized sweet, then cooled, and each churning divided into four parts. One was held overnight and churned, the average acidity being 0.14 per cent. To the others about 10 per cent lactic culture was added, and each was held overnight at such a temperature as to develop nearly 0.25, 0.31, and 0.35 per cent acid, respectively. When the acidity the next morning was less than the desired amount, it was increased to that point by the addition of culture. Scores for butter containing the desired amount of acidity are given in Table 4. In some cases the desired acidity was exceeded. The scores for the butter made from such cream are given in Table 5. The butter in this series was stored only at 0° to 20° F. For a period of two weeks during the sixth month the temperature of the room was as high as 20° a part of each day. Both Tables 4 and 5 show that deterioration increased as acidity of the cream increased.

TABLE 4.—*Scores of butter when fresh and after storage for 8 and 11 months at 0° to 20° F.*

[Seven churnings at each acidity.]

Acidity of cream	Fresh	After storage at 0° to 20° F. for—			
		Eight months		Eleven months	
		Score	Decrease	Score	Decrease
Per cent	*Points*	*Points*	*Points*	*Points*	*Points*
0.14	92.27	90.30	1.97	90.28	1.99
.25	92.71	90.10	2.61	89.83	2.88
.31	92.69	89.87	2.82	89.50	3.19
.35	92.58	89.57	3.01	88.87	3.71

TABLE 5.—*Scores of butter when fresh and after storage for eight months at 0° to 20° F.*

[Six churnings at each acidity.]

Acidity of cream		Fresh	After eight months at 0° to 20° F.	Decrease
Range	Average			
Per cent	*Per cent*	*Points*	*Points*	*Points*
0.15	0.150	92.40	90.09	2.31
0.27 to .29	.280	92.78	89.68	3.10
.34 to .39	.365	92.55	88.95	3.60
.40 to .45	.425	93.28	88.63	4.65

COMMERCIAL CHURNINGS

To compare the results of experiments with butter made in the laboratory with that made commercially, a compilation was made of the scores on storage butter [5] judged in the contest held by the National Creamery Buttermakers' Association in 1925 and 1926. The entries were divided into six groups according to the acidity of the cream when churned. In order to make as fair a comparison as possible, no entries were used that reported the acidity of cream when received as being higher than 0.2 per cent, and only those entries were used that gave all the data needed. This butter was held in a commercial warehouse at about 0° F. The storage period for the 1926 butter was about five months and for the 1925 butter somewhat less.

Table 6 shows the scores of the butter when fresh and after storage. When fresh, the butter that scored lowest was that made from the cream of lowest acidity to which no culture had been added.

TABLE 6.—*Average scores of butter in the National Creamery Buttermakers' Association cold-storage butter contest, 1925 and 1926*

[292 entries.]

Acidity of cream when churned	Samples	Average acidity when—		Average score of butter			Samples not decreasing in score during storage		Samples scoring 94 or higher after storage	
		Received	Churned	Fresh	After storage	Decrease				
Per cent	*Number*	*Per cent*	*Per cent*	*Points*	*Points*	*Points*	*Number*	*Per cent*	*Number*	*Per cent*
0.20 or less [1]	60	0.169	0.172	92.83	92.60	0.23	24	40.0	3	5.0
.20 or less [2]	74	.153	.186	93.28	92.77	.51	20	27.0	7	9.5
.21 to 0.25	77	.167	.231	93.16	92.52	.64	22	28.6	6	7.7
.26 to .30	52	.165	.287	93.43	92.59	.84	10	19.2	4	7.7
.31 to .35	17	.182	.331	93.11	92.08	1.03	3	17.6	0	0.0
.36 to .45	12	.164	.401	93.21	91.45	1.76	2	16.6	0	0.0

[1] No culture. [2] Culture used.

After storage, the average scores of the butter in the cream-acidity groups up to 0.3 per cent were very close. The average score for the 0.31 to 0.35 per cent acid group was approximately one-half point lower than the scores for the groups of less than 0.31 per cent acid, and the average score for the 0.36 to 0.45 per cent acid group was about 1 point lower. Table 6 shows that the greater the acidity of the cream the greater the deterioration in the butter. The percentage of samples that scored as high after storage as when fresh, or higher, ranged from 40 for the lowest acidity group to 16.6 for the highest acidity group. None of the butter in the groups of more than 0.3 per cent acid scored as high as 94 points after storage.

SUMMARY AND CONCLUSIONS

Butter made from cream with acidities of 0.15 to 0.31 per cent kept well in storage at 0° F. for 8 months. After 12 months at 0° butter from cream with 0.15 to 0.25 per cent acid had deteriorated less than that in the 0.28 and 0.31 per cent acid groups.

When the butter was held at 30° to 50° F. for four months the deterioration was greater in the butter made from cream of greater

[5] Data obtained through courtesy of the secretary of the association.

acidity than in that made from the less acid cream. Butter in the 0.31 per cent acid group lost about one-half point in score more than that in the 0.15 per cent acid group.

When butter, made from cream with acidities of 0.14 to 0.45 per cent, was stored at 0° to 20° F. for 8 and 11 months the deterioration was greater in the butter made from cream of greater acidity than in that made from the less acid cream.

When commercial butter, made from cream with acidities up to 0.45 per cent, was held at 0° F. for about 5 months the deterioration was greater in the butter made from cream of greater acidity than in that made from less acid cream. After storage, however, the butter in all acidity groups up to 0.3 per cent scored about the same; and the average score for the 0.31 to 0.35 per cent acid group was approximately one-half point lower and for the 0.36 to 0.45 per cent acid group about 1 point lower than the scores for the groups of less than 0.31 per cent acid.

Butter made from cream with an acidity as high as 0.31 per cent may be expected to keep well for as long as 8 months when stored at a temperature of 0° F. or lower. There appears to be no advantage, however, in making butter for storage from cream with an acidity as high as 0.31 per cent.

Ripening cream with a lactic culture even to low acidities improves the score of the butter when fresh, but the improvement is usually lost during storage.

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COMPARATIVE STRENGTH PROPERTIES OF WOODS GROWN IN THE UNITED STATES

BY

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UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D. C.

For sale by the Superintendent of Documents, Washington, D.C. Price 10 cents

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COMPARATIVE STRENGTH PROPERTIES OF WOODS GROWN IN THE UNITED STATES

By L. J. MARKWARDT [1]

Assistant in Charge, Section of Timber Mechanics, Forest Products Laboratory,[2] *Forest Service*

CONTENTS

FOREWORD

The information contained in this bulletin is of value in making comparisons of species of wood in order to determine the choice of species for specific uses. Technical terms have, as far as possible, been omitted from the body of the bulletin, and the various properties determined from over a quarter million tests have been combined into simple comparative figures. This bulletin supplements but does not supersede United States Department of Agriculture Bulletin 556, Mechanical Properties of Woods Grown in the United States, (*4*) [3] which presents the basic information from which the comparative figures have been derived. Since Bulletin 556 was issued additional tests have been made and some additional species have been tested. In all cases the comparative figures presented here are based on the latest available results. Bulletin 556 should be used when technical data on the properties of clear wood are required by engineers, archi-

[1] Acknowledgment is made to J. A. Newlin and T. R. C. Wilson of the Forest Product Laboratory for assistance in the preparation of this bulletin, and to W. A. Shewhart of the Bell Telephone laboratories for suggestions regarding variability analysis.

[2] Maintained by the Forest Service, United States Department of Agriculture, at Madison, Wis., in cooperation with the University of Wisconsin.

[3] Reference is made by italic numbers in parentheses to "Literature cited," p. 38.

tects, and others, or when, in the judgment of the user, it is more applicable than the comparative figures presented here.

Although this bulletin gives figures only on weight, shrinkage, and strength, it is of course evident that other properties and factors, such as resistance to decay, painting and finishing qualities, tendency to leach coloring matter, size and character of prevalent defects, marketing practice, and the like must also be considered in selecting a species or in determining the suitability of a wood for different uses. Attention is also called to the fact that, because of the considerable variation in properties of all species of wood, it is often possible to select individual pieces of a weak species exceeding in strength the average of a stronger one, and to segregate the wood of a species into classes according to weight and strength, so that each class may be directed to the uses for which the class is best suited. In this way the variability of wood may be turned from a liability to an asset.

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HISTORICAL

The strength of wood has always been an important factor in its use, but it is becoming even more significant with the increasing competition from other materials, the increasing production of new or little-used species, and the changing requirements of consuming markets. Considered broadly, three periods can be recognized in our forest history as affecting timber utilization: The land-clearing period, the timber-mining period, and the timber-crop period, which we are now entering.

During the so-called land-clearing period some of the best-known hardwoods, such as yellow poplar and black walnut, occupied the richer agricultural regions in the East before giving way to the plow. Together with the softwoods they furnished from selected logs abundant material to supply the building and other needs of the time. Consequently, lumber was used in greater quantities and in better grades than were actually required. Often the best species found their way into commonplace uses, as, for example, the employment of black walnut for floor joists, fence rails, and the like. Utilization of local supplies prevailed, and long expensive hauls were not required. While these forests were giving way to agriculture, timber was a by-product of land clearing, and economy was neither practiced nor necessary.

The period of timber mining, which followed, furnished the material to meet much of the industrial growth of the country. Only the most far-seeing could realize that such extensive forests as the magnificent white pine stand of Michigan and Wisconsin were exhaustible. The abundance of desirable species admirably adapted to the needs of the country, the short haul to market, and cheap labor resulted in a period of timber use with a per capita consumption far exceeding that of most other countries. The Nation became wood dependent, and timber, like ore, was removed without thought of replacement. As in the land-clearing period, lumber was still used in better grades than necessary, although there was a gradual awakening to the need of using wood more efficiently.

We are now on the threshold of the timber-crop period, which is based on the conception that timber is reproducible, like any other crop, except that the period of rotation is longer. Progressive lumber operators are carefully studying how to keep their forest lands actively growing timber, and a few are now operating on a sustained-yield basis. If forestry is practiced on land not suited to ordinary crops and if timber is efficiently utilized, the United States can reasonably be expected to meet most of its future timber requirements at least after an initial adjustment period.

NEED FOR INFORMATION ON PROPERTIES

Timber utilization in the present forest-crop period with its longer haul to market demands a higher degree of efficiency than that of previous periods, since modern competition necessitates that all materials be used to their best advantage to maintain their markets. A first requirement of efficient use is a knowledge of the properties. This knowledge is of value in several ways.

The increasing scarcity of certain species of timber which had become more or less standard in various wood-using industries, the wider competition in practically all markets, increased transportation facilities, and other factors are opening the field for other species. Through long use the properties which have made a species more or less standard are quite well understood, but it is not so generally known to what extent other available species possess these same properties, and to what extent they might supplement the established species.

Another need for information on properties is in the introduction of so-called little-used species. In the pushing of timber production into new regions, new species are encountered. Good crop management as conceived by many foresters and wood-utilization experts necessitates, at least so far as lumber and timber purposes are concerned, that certain species, such as western hemlock and white fir, be logged along with the well-known woods with which they grow rather than be left to dominate and propagate the succeeding crop. A knowledge of the properties is one of the first requirements in the use of alternate species and in the use of little-known woods.

PURPOSE

Wood utilization in the future must depend more and more on the true value of the product as determined by exact information on the properties rather than on rule-of-thumb practice. This bulletin presents exact information for the comparison of the strength properties of many of our native species. Other publications have usually presented strength data in technical terms familiar principally to architects and engineers, but here the technical values are combined into simplified comparative figures, which are more readily intelligible to the average person. For many purposes these simplified comparative figures will be found as useful as the technical values on which they are based.

The figures presented are especially applicable for two types of use (1) that relating to the alternation of one species with another and (2) that involved in selecting species for uses in which the strength requirements are known. The significance of the figures is shown and examples of their use are given.

PROPERTIES OTHER THAN STRENGTH

Although this bulletin presents figures only on weight, shrinkage, and strength, it should not be overlooked that other properties and factors must also be considered in the utilization of wood, and that the value of a wood for a given use is ordinarily based upon a combination of properties rather than upon a single property. Among other properties which may be of importance are nail-holding ability; splitting; tendency to warp; gluing qualities; painting and finishing characteristics; resistance to decay, weathering, and insects; insulating properties; and acid resistance. Information on these latter properties, however, does not come within the scope of this bulletin.[4]

The relative usefulness of any lumber may also depend upon the characteristics of the stock in its entirety, as well as upon the properties of the clear wood, and may be influenced by sizes available, degree of seasoning, and marketing practice. Thus the mechanical properties of the clear wood may indicate that a species is an excellent wood for boxes for bulk commodities, but the lumber may be unsuited for such use because of a characteristic tendency of the knots to loosen and fall out. Furthermore, the advantage of inherently low shrinkage or high nail-holding power in a species may be lost through the method of marketing or the use of the species before it is sufficiently dry.

IMPORTANCE OF STRENGTH

There are few uses of wood in which its serviceability is not somewhat dependent upon one or more of its strength properties. Airplane wing beams, floor joists, and wheel spokes typify familiar uses in which strength is the principal consideration. Often strength in combination with other important properties is required. Thus, telephone poles, railroad ties, and bridge stringers require not only the capacity to carry loads, but also resistance to decay. In addition, a large number of uses of wood, not usually thought of in connection with strength, are dependent, at least to some degree, on strength properties. For example, finish and trim for buildings should be sufficiently hard to prevent easy marring; window sash must have screw-holding ability to permit secure attachment of hardware, as well as adequate stiffness to prevent springing when the window is opened and closed. Even matches must have strength to prevent their breaking when being lighted. Information on strength is therefore essential not only for the design of such engineering structures as airplanes, buildings, and bridges, but also as a guide for the selection of suitable species for a great variety of uses, whether it be the soft, light woods or the inherently stronger ones that are required.

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[4] Information on properties other than those presented in this bulletin may be obtained from the Forest Products Laboratory, Madison, Wis.

EXPLANATION OF "STRENGTH"

Much confusion exists in regard to the meaning of "strength." In its broader sense, strength includes all the properties which enable wood to resist different forces or loads. In its more restricted sense, strength may apply to any one of the mechanical properties; in which event, the name of the property under consideration should be stated. If the several strength properties had the same relation to each other in all species, a wood which excelled in one strength property would be higher in all, and misunderstandings about the word "strength" would be less likely to occur. But such is not the case. A wood may rank better in one kind of resistance to load than in another. Longleaf pine averages higher than white oak in compressive strength (endwise), but is lower in hardness. Hence, it can not be said that longleaf pine is "stronger" than white oak without stating the kind of strength referred to. To be precise, in making a comparison of species, it is necessary to consider the kind of strength properties or combination of properties essential to the particular use, since different kinds of strength are essential in different uses. Thus, longleaf pine, because of its higher compressive strength (endwise), is superior to oak for use in short posts that carry heavy endwise loads, whereas oak, because of greater hardness, is superior in resistance to the wear and marring to which some floors are subjected.

NATURE AND SCOPE OF STRENGTH FIGURES

Several publications (*3*, *4*, *5*, and *10*) present figures upon the strength properties of wood for small clear specimens and for structural timbers containing defects. Although such technical strength figures can be applied to all strength problems, there are, nevertheless, many uses of wood involving the selection of suitable species where the conversion of technical figures into simple comparative figures as is done in this bulletin would serve equally well. Since the strength figures given are composite values, or, in effect, index numbers, they are mainly for comparative purposes and are consequently not suitable for calculating the load-carrying capacity of wood.

The comparative figures for 164 native species are given in Table 1. The figures are based on an extensive series of tests on small clear specimens of wood begun by the Forest Products Laboratory in 1910. Each kind of wood, with few exceptions is represented by five or more trees. Some of the specimens were tested green from the tree, others after thorough seasoning (*1*). Collectively, the results include for each species figures on over 25 strength and other properties obtained from 10 different kinds of tests (*4*).

The more important test results for each species have been averaged and combined into comparative or composite figures which represent six properties, namely, bending strength, compressive strength (endwise), stiffness, hardness, shock resistance, and volumetric shrinkage. Definite figures for these essential properties are presented in Table 1, from which numerical comparisons may be made among the different species. Average figures on specific gravity, weight per cubic foot, and radial and tangential shrinkage (p. 20) are also included. The methods of computing the comparative figures of Table 1 are described in Appendix 2.

TABLE 1.—*Average comparative properties of the clear wood of species grown in the United States* [1]

[For definition of terms and discussion of table see "Explanation of Table 1" in text]

Common and botanical name of species	Trees tested	Specific gravity, oven dry, based on volume when green	Weight per cubic foot: Green	Weight per cubic foot: At 12 per cent moisture content	Shrinkage from green to oven-dry condition based on dimensions when green: Radial	Shrinkage: Tangential	Shrinkage: Volumetric (composite value)[2]	Composite strength values [2]: Bending strength	Compressive strength (endwise)	Stiffness	Hardness	Shock resistance
1	2	3	4	5	6	7	8	9	10	11	12	13
	Number		*Pounds*	*Pounds*	*Per cent*	*Per cent*	*Comparative figure*	*Comparative figure*	*Comparative figure*	*Comparative figure*	*Comparative figure*	*Comparative figure*
Hardwoods:												
Alder, red (Alnus rubra)	6	0.37	46	28	4.4	7.3	123	76	82	139	48	71
Apple (Malus pumila var.)	10	.61	55	47	5.6	10.1	170	85	75	139	119	146
Ash, biltmore white (Fraxinus biltmoreana)	5	.51	45	38	4.2	6.9	121	107	108	156	104	114
Ash, black (Fraxinus nigra)	11	.46	53	34	5.0	7.8	144	77	68	126	64	122
Ash, blue (Fraxinus quadrangulata)	5	.53	46	40	3.9	6.5	113	109	107	139	119	147
Ash, green (Fraxinus pennsylvanica lanceolata)	10	.53	49	40	4.6	7.1	122	107	106	157	107	116
Ash, Oregon (Fraxinus oregona)	3	.50	46	38	4.1	8.1	129	88	88	143	94	123
Ash, pumpkin (Fraxinus profunda)	3	.48	46	36	3.7	6.3	113	86	85	118	103	87
Ash, white (Fraxinus americana)	23	.55	48	42	4.9	7.9	132	113	106	168	107	153
Ashes, commercial white (ave. of 4 species [3])	43	.54	48	41	4.6	7.5	126	110	106	161	108	139
Aspen (Populus tremuloides)	11	.35	43	27	3.5	6.7	111	63	58	107	31	67
Aspen, largetooth (Populus grandidentata)	10	.35	43	27	3.3	7.9	116	66	69	130	38	63
Basswood (Tilia glabra)	8	.32	41	26	6.6	9.3	158	61	62	126	31	54
Beech (Fagus grandifolia)	17	.56	54	45	5.1	11.0	162	102	94	169	96	135
Beech, blue (Carpinus caroliniana)	12	.58	53	48	5.7	11.4	184	76	66	114	116	296

Birch, Alaska white (Betula neoalaskana)	10	.49	48	38	6.5	9.9	166	89	86	161	61	126
Birch, gray (Betula populifolia)	5	.45	46	35	5.2		147	61	53	85	54	147
Birch, paper (Betula papyrifera)	10	.48	50	39	6.3	8.6	158	78	68	137	58	158
Birch, sweet (Betula lenta)	10	.60	57	46	6.5	8.5	154	117	105	207	104	159
Birch, yellow (Betula lutea)	17	.55	57	43	7.2	9.2	166	106	98	174	86	171
Blackwood (Avicennia nitida)	6	.83	74	58	6.2	9.7	157	123	120	185	185	167
Buckeye, yellow (Aesculus octandra)	5	.33	49	25	3.5	7.8	118	58	56	112	31	52
Bustic (Dipholis salicifolia)	1	.86	77	62								
Butternut (Juglans cinerea)	10	.36	46	27	3.3	6.1	100	64	68	115	40	80
Buttonwood (Conocarpus erecta)	7	.69	64	50	5.4	8.5	144	89	106	159	122	78
Cascara (Rhamnus purshiana)	5	.50	50	36	3.2	4.6	77	71	79	93	86	140
Catalpa, hardy (Catalpa speciosa)	15	.38	41	29	2.5	4.9	73	63	59	110	43	95
Cherry, black (Prunus serotina)	5	.47	46	35	3.7	7.1	113	93	100	150	72	112
Cherry, pin (Prunus pennsylvanica)	5	.36	33	28	2.8	10.3	129	62	63	117	41	77
Chestnut (Castanea dentata)	10	.40	55	30	3.4	6.7	111	68	70	112	50	69
Chinquapin, golden (Castanopsis chrysophylla)	5	.42	61	32	4.6	7.4	128	83	76	125	62	95
Cottonwood, black (Populus trichocarpa)	5	.32	46	24	3.6	8.6	123	60	61	119	29	59
Cottonwood, eastern (Populus deltoides)	5	.37	49	28	3.9	9.2	138	62	64	123	36	73
Dogwood (Cornus florida)	5	.64	64	51	7.1	11.3	194	100	101	124	154	192
Dogwood, Pacific (Cornus nuttallii)	5	.58	55	45	6.4	9.6	168	86	93	142	116	154
Elder, blueberry (Sambucus coerulea)	5	.46	65	36	4.4	9.0	149	72	76	115	68	109
Elm, American (Ulmus americana)	12	.46	54	36	4.2	9.5	145	85	74	130	66	123
Elm, rock (Ulmus racemosa)	10	.57	54	44	4.8	8.1	137	106	97	148	104	189
Elm, slippery (Ulmus fulva)	6	.48	56	37	4.9	8.9	138	92	89	140	72	162
Fig, golden (Ficus aurea)	1	.44	51	31				61	66	67		65
Gum, black (Nyssa sylvatica)	5	.46	45	35	4.4	7.7	133	83	78	118	78	80
Gum, blue (Eucalyptus globulus)	5	.62	70	52	7.6	15.3	226	134	148	233	132	134
Gum, red (Liquidambar styraciflua)	10	.44	50	34	5.2	9.9	150	86	77	134	60	99
Gum, tupelo (Nyssa aquatica)	6	.46	56	35	4.2	7.6	122	82	87	127	78	81
Gumbo-limbo (Bursera simaruba)	5	.30	38	22	2.3	3.6	77	39	38	66	30	32
Hackberry (Celtis occidentalis)	6	.49	50	37	4.8	8.9	138	76	72	108	74	145
Haw, pear (Crataegus tomentosa)	2	.62	63	48				95	87	107	127	193
Hickory, bigleaf shagbark (Hicoria laciniosa)	19	.62	62	48	7.6	12.6	195	126	105	165		308
Hickory, bitternut (Hicoria cordiformis)	11	.60	63	46				127	127	170		227
Hickory, mockernut (Hicoria alba)	19	.64	64	51	7.8	11.0	182	135	122	185		270

[1] Based on tests of small clear specimens, 2 by 2 inches in section except radial and tangential shrinkage which are based on width measurements of pieces 1 inch thick, 4 inches wide, and 1 inch long. Bending specimens are 30 inches long; others are shorter, depending on kind of test. This table is for use in comparing species either in the form of clear lumber or in grades containing like defects, except structural material. Structural material which conforms to American lumber standards should be compared by means of allowable working stresses, values for which are presented in the Appendix 1.

[2] The method used in establishing the composite values, each of which is based on combinations of several similar properties is presented in Appendix 2

[3] *Fraxinus biltmoreana*, *F. quadrangulata*, *F. pennsylvanica lanceolata*, and *F. americana*.

TABLE 1.—*Average comparative properties of the clear wood of species grown in the United States*—Continued

[For definition of terms and discussion of table see "Explanation of Table 1" in text]

Common and botanical name of species	Trees tested	Specific gravity, oven dry, based on volume when green	Weight per cubic foot		Shrinkage from green to oven-dry condition based on dimensions when green			Composite strength values				
			Green	At 12 per cent moisture content	Radial	Tangential	Volumetric (composite value)	Bending strength	Compressive strength (endwise)	Stiffness	Hardness	Shock resistance
1	2	3	4	5	6	7	8	9	10	11	12	13
Hardwoods—Continued.	*Number*		*Pounds*	*Pounds*	*Per cent*	*Per cent*	*Comparative figure*	*Comparative figure*	*Comparative figure*	*Comparative figure*	*Comparative figure*	*Comparative figure*
Hickory, nutmeg (Hicoria myristicaeformis)	5	0.56	60	42				111	104	147		221
Hickory, pignut (Hicoria glabra)	60	.66	64	53	7.2	11.5	182	144	129	198		308
Hickory, shagbark (Hicoria ovata)	24	.64	64	51	7.0	10.5	170	133	123	185		258
Hickory, water (Hicoria aquatica)	2	.61	68	43				128	116	185		189
Hickories, pecan (ave. of 4 species [4])	23	.59	62	45	4.9	8.9	137	120	116	165	142	207
Hickories, true (ave. of 4 species [5])	122	.65	63	51	7.3	11.4	182	138	123	188		292
Hickories, pecan and true (ave. of 8 species [6])	145	.64	63	50	7.2	11.3	180	135	122	184	142	279
Holly (Ilex opaca)	5	.50	57	40	4.5	9.5	155	76	71	102	86	124
Hop-hornbeam (Ostrya virginiana)	5	.63	60	50	8.2	9.6	183	101	100	150	126	169
Inkwood (Exothea paniculata)	2	.73	71	56	6.6	10.9	184	124	110	182	181	154
Ironwood, black (Krugiodendron ferreum)	4	1.04	86	80	6.2	8.0	125	157	168	254		130
Laurel, mountain (Kalmia latifolia)	5	.62	62	48	5.6	8.8	144	97	100	110	143	113
Locust, black (Robinia pseudoacacia)	3	.66	58	48	4.4	6.9	103	157	168	220	161	170
Locust, honey (Gleditsia triacanthos)	6	.60	61	44	4.2	6.6	107	112	111	153	155	144
Madroño (Arbutus menziesii)	6	.58	60	46	5.4	11.9	173	86	88	117	114	93
Magnolia, cucumber (Magnolia acuminata)	5	.44	49	34	5.2	8.8	137	90	88	175	57	103
Magnolia, evergreen (Magnolia grandiflora)	2	.46	62	35	5.4	6.6	122	81	73	136	80	141

Magnolia, mountain (Magnolia fraseri)	5	.40	47	31	4.4	7.5	126	76	73	142	51	81
Mangrove (Rhizophora mangle)	4	.89	77	67	5.4	----	123	176	155	270	251	164
Maple, bigleaf (Acer macrophyllum)	5	.44	47	34	3.7	7.1	113	83	86	132	73	78
Maple, black (Acer nigrum)	1	.52	54	40	4.8	9.3	140	93	89	149	97	135
Maple, red (Acer rubrum)	14	.49	50	38	4.0	8.2	128	93	87	158	79	110
Maple, silver (Acer saccharinum)	5	.44	45	33	3.0	7.2	114	69	71	106	65	93
Maple, striped (Acer pennsylvanicum)	4	.44	37	32	3.2	8.6	121	78	73	135	59	100
Maple, sugar (Acer saccharum)	22	.57	56	44	4.9	9.5	147	114	106	178	115	138
Mastic (Sideroxylon foetidissimum)	5	.89	77	65	6.1	7.5	123	112	125	183	208	97
Myrtle, Oregon (Umbellularia californica)	5	.51	54	39	2.8	8.1	116	72	76	89	106	144
Oak, black (Quercus velutina)	8	.56	63	43	4.5	9.7	142	98	91	146	102	128
Oak, bur (Quercus macrocarpa)	5	.58	62	45	4.4	8.8	129	82	81	104	112	114
Oak, California black (Quercus kelloggii)	10	.51	66	40	3.6	6.6	115	69	72	95	99	76
Oak, canyon live (Quercus chrysolepis)	3	.70	71	54	5.4	9.5	158	110	127	159	181	131
Oak, chestnut (Quercus montana)	5	.57	61	46	5.5	9.7	162	102	94	166	90	107
Oak, laurel (Quercus laurifolia)	5	.56	65	44	4.0	9.9	173	94	90	169	99	120
Oak, live (Quercus virginiana)	5	.81	76	62	6.6	9.5	152	142	130	228	240	148
Oak, Oregon white (Quercus garryana)	10	.64	69	51	4.2	9.0	133	86	89	107	153	127
Oak, pin (Quercus palustris)	5	.58	63	44	4.3	9.5	143	96	95	167	111	152
Oak, post (Quercus stellata)	10	.60	63	47	5.4	9.8	159	99	89	143	122	130
Oak, red (Quercus borealis)	33	.56	63	44	4.0	8.2	131	99	88	164	103	143
Oak, Rocky Mountain white (Quercus utahensis)	3	.62	62	51	4.1	7.2	121	70	67	78	137	78
Oak, scarlet (Quercus coccinea)	5	.60	62	47	4.6	9.7	140	115	107	181	120	175
Oak, southern red (Quercus rubra)	4	.52	62	41	4.5	8.7	153	83	76	153	86	83
Oak, swamp red (Quercus rubra pagodaefolia)	3	.61	68	48	5.2	10.8	163	131	122	215	123	162
Oak, swamp chestnut (Quercus prinus)	4	.60	65	47	5.9	9.2	180	100	95	171	103	132
Oak, swamp white (Quercus bicolor)	1	.64	69	50	5.5	10.6	172	122	114	184	122	165
Oak, water (Quercus nigra)	5	.56	63	44	4.2	9.3	154	110	95	196	101	138
Oak, white (Quercus alba)	20	.60	62	48	5.3	9.0	153	102	96	152	108	127
Oak, willow (Quercus phellos)	2	.56	67	49	5.0	9.6	175	96	86	167	106	116
Oaks, commercial red (ave. of 9 species [7])	70	.56	64	44	4.2	9.0	143	101	92	168	103	139
Oaks, commercial white (ave. of 6 species [8])	45	.59	63	47	5.3	9.3	155	99	93	149	109	125
Oaks, commercial red and white (ave. of 15 species [9])	115	.57	63	45	4.7	9.1	148	100	92	161	105	134

[4] *Hicoria cordiformis*, *H. myristicaeformis*, *H. aquatica*, and *H. pecan*.
[5] *Hicoria laciniosa*, *H. alba*, *H. glabra*, and *H. ovata*.
[6] Species under footnotes 4 and 5 combined.
[7] *Quercus velutina*, *Q. laurifolia*, *Q. palustris*, *Q. borealis*, *Q. coccinea*, *Q. rubra*, *Q. rubra pagodaefolia*, *Q. nigra*, and *Q. phellos*.
[8] *Quercus macrocarpa*, *Q. montana*, *Q. stellata*, *Q. prinus*, *Q. bicolor*, and *Q. alba*.
[9] Species under footnotes 7 and 8 combined.

TABLE 1.—*Average comparative properties of the clear wood of species grown in the United States*—Continued

[For definition of terms and discussion of table see "Explanation of Table 1" in text]

Common and botanical name of species	Trees tested	Specific gravity, oven dry, based on volume when green	Weight per cubic foot: Green	Weight per cubic foot: At 12 per cent moisture content	Shrinkage from green to oven-dry condition based on dimensions when green: Radial	Shrinkage: Tangential	Shrinkage: Volumetric (composite value)	Composite strength values: Bending strength	Compressive strength (endwise)	Stiffness	Hardness	Shock resistance
1	2	3	4	5	6	7	8	9	10	11	12	13
	Number		*Pounds*	*Pounds*	*Per cent*	*Per cent*	*Comparative figure*	*Comparative figure*	*Comparative figure*	*Comparative figure*	*Comparative figure*	*Comparative figure*
Hardwoods—Continued.												
Osage-orange (Toxylon pomiferum)	1	.76	62	—	—	—	89	—	—	—	—	—
Palmetto, cabbage (Sabal palmetto)	5	.37	54	27	—	—	250	40	36	55	21	49
Paradise-tree (Simarouba glauca)	4	.33	37	24	2.2	5.2	82	42	44	86	32	21
Pecan (Hicoria pecan)	5	.60	61	47	4.9	8.9	137	110	104	162	142	156
Persimmon (Diospyros virginiana)	5	.64	63	52	7.5	10.8	183	122	116	172	162	136
Pigeon-plum (Coccolobis laurifolia)	5	.77	73	55	4.4	7.8	145	108	118	184	189	114
Poisonwood (Metopium toxiferum)	4	.51	54	37	4.2	7.2	115	69	57	99	62	49
Poplar, balsam (Populus balsamifera)	10	.30	40	23	3.0	7.1	104	48	48	95	25	43
Poplar, yellow (Liriodendron tulipifera)	11	.38	38	28	4.0	7.1	119	71	68	135	40	58
Rhododendron, great (Rhododendron maximum)	5	.59	62	40	6.3	8.7	158	85	91	100	104	104
Sassafras (Sassafras variifolium)	5	.42	44	32	4.0	6.2	103	71	71	103	60	98
Serviceberry (Amelanchier canadensis)	5	.66	61	52	6.7	10.8	183	121	116	181	131	186
Silverbell (Halesia carolina)	5	.42	44	32	3.8	7.6	122	74	72	133	53	81
Sourwood (Oxydendrum arboreum)	5	.50	53	38	6.3	8.9	152	94	87	169	83	108
Stopper, red (Eugenia confusa)	3	.83	73	61	6.2	9.1	140	145	137	197	—	162
Sugarberry (Celtis laevigata)	5	.47	48	36	5.0	7.3	126	74	74	103	83	116
Sumach, staghorn (Rhus hirta)	5	.45	41	33	—	—	—	74	76	94	64	116
Sycamore (Platanus occidentalis)	10	.46	52	35	5.1	7.6	136	74	76	129	64	78
Walnut, black (Juglans nigra)	5	.51	58	39	5.2	7.1	116	111	113	167	88	124
Walnut, little (Juglans rupestris)	1	.53	55	40	4.4	4.6	101	91	86	118	—	126

Willow, black (Salix nigra)	10	.34	50	26	2.5	7.8	126	45	41	70	35	91
Willow, western black (Salix lasiandra)	5	.39	50	31	2.9	9.0	132	67	63	127	50	104
Witch-hazel (Hamamelis virginiana)	5	.56	59	43	----	----	188	108	88	129	107	187
Softwoods:												
Cedar, Alaska (Chamaecyparis nootkatensis)	8	.42	36	31	2.8	6.0	91	80	87	136	53	93
Cedar, incense (Libocedrus decurrens)	8	.35	45	26	3.3	5.7	81	70	81	97	47	53
Cedar, Port Orford (Chamaecyparis lawsoniana)	14	.40	36	29	4.6	6.9	106	82	90	168	48	79
Cedar, eastern red (Juniperus virginiana)	5	.44	37	33	3.1	4.7	78	67	87	80	81	114
Cedar, western red (Thuja plicata)	15	.31	27	23	2.4	5.0	76	60	74	108	38	52
Cedar, northern white (Thuja occidentalis	5	.29	28	22	2.1	4.7	69	50	52	78	30	47
Cedar, southern white (Chamaecyparis thyoides)	10	.31	26	23	2.8	5.2	83	53	61	93	35	51
Cypress, southern (Taxodium distichum)	26	.42	50	32	3.8	6.2	104	79	92	136	52	76
Douglas fir (Pseudotsuga taxifolia) (coast type)	34	.45	38	34	5.0	7.8	121	90	107	181	59	81
Douglas fir (Pseudotsuga taxifolia), (inland empire type)	10	.41	37	31	4.1	7.6	112	80	90	159	58	72
Douglas fir (Pseudotsuga taxifolia) (Rocky Mountain type)	10	.40	35	30	3.6	6.2	103	75	83	142	52	67
Fir, alpine (Abies lasiocarpa)	5	.31	28	23	2.5	7.1	92	51	57	94	33	36
Fir, balsam (Abies balsamea)	5	.34	45	26	2.8	6.6	103	59	67	118	31	50
Fir, corkbark (Abies arizonica)	10	.28	29	21	2.8	7.4	90	51	57	104	27	38
Fir, lowland white (Abies grandis)	10	.37	44	28	3.2	7.2	105	72	82	156	43	72
Fir, noble (Abies nobilis)	9	.35	30	26	4.5	8.3	126	74	76	150	39	68
Fir, California red (Abies magnifica)	5	.37	48	27	3.8	6.9	114	78	74	134	52	71
Fir, silver (Abies amabilis)	6	.35	36	27	4.5	10.0	142	70	76	147	37	70
Fir, white (Abies concolor)	20	.35	47	26	3.2	7.0	95	72	73	127	42	60
Firs, white (ave. of 4 species [10])	45	.35	41	26	3.8	7.9	110	72	76	141	41	66
Hemlock, eastern (Tsuga canadensis)	20	.38	50	28	3.0	6.8	98	72	79	121	51	67
Hemlock, mountain (Tsuga mertensiana)	10	.43	44	33	4.4	7.4	114	81	88	131	64	99
Hemlock, western (Tsuga heterophylla)	18	.38	41	29	4.3	7.9	120	74	84	144	50	73
Juniper, alligator (Juniperus pachyphloea)	3	.48	42	36	2.7	3.6	73	63	76	60	107	79
Larch, western (Larix occidentalis)	13	.48	48	36	4.2	8.1	129	89	104	153	64	81
Pine, jack (Pinus banksiana)	5	.39	50	30	3.4	6.5	102	64	73	111	48	78
Pine, jeffrey (Pinus jeffreyi)	5	.37	47	28	4.4	6.7	103	68	71	116	44	63
Pine, limber (Pinus flexilis)	2	.37	39	28	2.4	5.1	80	69	69	107	39	54
Pine, loblolly (Pinus taeda)	10	.50	54	38	5.5	7.5	127	93	104	166	62	93
Pine, lodgepole (Pinus contorta)	28	.38	39	29	4.5	6.7	114	67	74	128	41	60

[10] *Abies grandis*, *A. nobilis*, *A. amabilis*, and *A. concolor*.

TABLE 1.—*Average comparative properties of the clear wood of species grown in the United States*—Continued

[For definition of terms and discussion of table see "Explanation of Table 1" in text]

Common and botanical name of species	Trees tested	Specific gravity, oven dry, based on volume when green	Weight per cubic foot		Shrinkage from green to oven-dry condition based on dimensions when green			Composite strength values				
			Green	At 12 per cent moisture content	Radial	Tangential	Volumetric (composite value)	Bending strength	Compressive strength (endwise)	Stiffness	Hardness	Shock resistance
1	2	3	4	5	6	7	8	9	10	11	12	13
Softwoods—Continued.	*Number*		*Pounds*	*Pounds*	*Per cent*	*Per cent*	*Comparative figure*	*Comparative figure*	*Comparative figure*	*Comparative figure*	*Comparative figure*	*Comparative figure*
Pine, longleaf (Pinus palustris)	34	.55	50	41	5.3	7.5	124	106	123	189	76	103
Pine, mountain (Pinus pungens)	5	.49	54	37	3.4	6.8	107	91	93	151	64	92
Pine, northern white (Pinus strobus)	18	.34	36	25	2.3	6.0	83	63	67	119	35	55
Pine, Norway (Pinus resinosa)	5	.44	42	34	4.6	7.2	116	85	91	163	46	84
Pine, pitch (Pinus rigida)	10	.45	50	34	4.0	7.1	110	80	76	146	56	96
Pine, pond (Pinus rigida serotina)	5	.50	49	38	5.1	7.1	115	89	103	154	64	90
Pine, sand (Pinus clausa)	5	.45	38	34	3.9	7.3	104	86	89	135	63	86
Pine, shortleaf (Pinus echinata)	12	.49	51	38	5.1	8.2	128	97	104	170	68	111
Pine, slash (Pinus caribaea)	10	.64	56	48	5.8	8.2	131	116	126	195	93	105
Pine, sugar (Pinus lambertiana)	9	.35	51	25	2.9	5.6	79	64	68	112	38	55
Pine, western white (Pinus monticola)	14	.36	35	27	4.1	7.4	118	69	75	137	35	65
Pine, western yellow (Pinus ponderosa)	31	.38	45	28	3.9	6.3	97	65	69	112	41	58
Piñon (Pinus edulis)	3	.50	51	37	4.6	5.2	99	60	75	108	73	65
Redwood [11] (Sequoia sempervirens)	5	.41	55	30	2.7	4.2	65	90	104	134	59	70
Spruce black (Picea mariana)	5	.38	32	28	4.1	6.8	112	68	70	143	40	82
Spruce, Engelmann (Picea engelmannii)	10	.31	39	23	3.4	6.6	102	55	57	100	32	45
Spruce, red (Picea rubra)	11	.38	34	28	3.8	7.8	117	72	80	138	41	68
Spruce, Sitka (Picea sitchensis)	25	.37	33	28	4.3	7.5	116	72	75	144	44	76
Spruce, white (Picea glauca)	15	.37	35	28	4.7	8.2	134	68	70	123	37	67
Spruces, (ave. of red, white, and Sitka [12])	51	.37	34	28	4.3	7.7	121	71	74	136	42	71

Tamarack (Larix laricina)	5	.49	47	37	3.7	7.4	128	84	96	147	53	85
Yew, Pacific (Taxus brevifolia)	5	.60	54	44	4.0	5.4	96	115	112	121	138	170
Percentage estimated probable variation of species average when based on 5 trees [13]		2.1			5.2	4.0	3.9	2.5	3.3	3.2	2.8	5.0
Percentage estimated probable variation of an individual piece		8					12	12	14	18	16	20

[11] The trees on which these values are based were somewhat higher in density than the general average for the species. It is, therefore, very probable that further tests which are now under way will slightly lower the present figures, although it is not expected that this will necessitate any change in the working stresses recommended for structural timber as given in Table 2.

[12] *Picea rubra*, *P. sitchensis*, and *P. glauca*.

[13] For percentage estimated variation of species when based on different number of trees see Table 6.

VARIABILITY

Variability is common to all materials. If one tests pieces of wire from a roll, the loads necessary to pull the wire apart will vary for the different pieces. In the same way, the breaking strengths of different pieces of the same kind of string or rope will not be the same. Materials, however, differ considerably in the amount of variation or the spread of values.

Everyone who has handled and used lumber has observed that no two pieces, even of the same species, are exactly alike. The differences most commonly recognized are in the appearance, but differences in the weight and in the strength properties are of even greater importance. Fortunately, appearance and weight are related to strength. This relation, which is very definite in some species, affords the basis of grading and selecting wood for strength.

In determining the strength properties of wood many individual specimens of each species are tested, and consequently many individual test values are obtained. It would be very laborious and confusing to present the values for each individual test. The figures in Table 1 are, therefore, average values from tests on specimens selected to represent the different species of wood.

The strength properties of individual pieces may vary considerably from the averages shown. Therefore, the fact that one species of wood averages higher than another in a certain property does not mean that every piece of that species will be better than every piece of the other species. A percentage figure is shown in the last line of Table 1 to indicate the range above and below the average which may be expected to include half of all the material of a species.

Because of the variation among individual specimens, the more tests made on a species the greater is the probability that the average obtained will represent the true average. The number of test specimens must be limited, however, because of the expense of determining the properties, and as a result units of five trees have, in general, been used to obtain the test figure for a wood from any one site or locality.

For the more important species, two and often more 5-tree units representing different localities have been tested. The tests vary in number from about a hundred to many thousand for a species, making a total of over a quarter million for all species studied. The present figures (Table 1) are the best available determinations of the true averages, although the figures for the less important species, which are based on fewer tests, would be more subject to change on additional testing than those for the common species.

For the foregoing reason, and since individual pieces of wood or lots of material purchased for any use vary from the averages, too much emphasis should not be placed on small differences in average figures. The importance of such differences, however, will depend largely on the use to which the wood is put. Detailed information on the range of variations to be expected and a discussion of their significance are presented in Appendix 3.

SELECTION FOR PROPERTIES

The fact that a piece of wood differs in properties from another of the same species often makes it more suitable for a given use. This suggests the possibility of selecting pieces to meet given requirements. For example, selection may be made at the sawmill so that the heavier, harder, and stronger pieces go into structural timbers, flooring, or other uses for which the higher measure of these properties particularly adapt them, while the lightweight pieces may preferably be used for such purposes as trim or heat insulation; or selection may be made at the lumber yard when material of either high or low weight is required. By means of selective methods the variability of wood can be made an asset. Selection on the basis of freedom from defects is a common practice. Selection on the basis of quality of clear wood is much less common, but is frequently very desirable.

Aside from actual strength tests, the specific gravity or density gives the best indication of the strength properties of any piece of wood. Within any species there exists a relatively small range in the strength of pieces of like density.

When different species are considered, the range in strength for pieces of like density may be quite large. To illustrate the difference in density-strength relations between species, consider the values for Douglas fir (coast type) and red gum in Table 1. These woods are about equal in weight when dry per unit volume as shown by their specific gravities, but Douglas fir averaged 39 per cent higher in compressive strength than red gum and 18 per cent lower in shock resistance.

It may be shown, likewise, that certain species of wood of medium density are equal in some properties to species of higher density. Douglas fir (coast type) with only three-fourths the density of commercial white oak is about equal to the oak in bending strength and compressive strength, and excels it in stiffness. Hence, Douglas fir is higher for its weight in these properties than white oak. In hardness and shock resistance, however, white oak averages much higher than Douglas fir.

HOW TO USE THE COMPARATIVE STRENGTH FIGURES

The strength figures in Table 1 (columns 9 to 13) are not percentages but are index numbers. They have no significance other than to give relative position in comparing species of wood for any specific use with respect to the several properties listed. The figures on weight and radial and tangential shrinkage, on the other hand, are in unit terms which can be used directly in making calculations or estimates.

In order properly to interpret and apply the figures in a comparison of species, one should be familiar with the requirements of his particular use. Unfortunately, no thorough study has been made to determine the properties essential to most uses, although in many cases much general information is available concerning them. Long usage has in some cases established what properties are required, but opinion frequently differs as to their importance. The most effective application of the figures, therefore, calls for judgment.

WORKING STRESSES RECOMMENDED FOR COMPARING STRUCTURAL MATERIAL

For comparing structural material of grades in which the size, location, and number of defects are limited with reference to their effect on strength, the allowable working stresses of Table 2 (Appendix 1) are recommended in preference to the figures of Table 1. However, the figures of Table 1, although primarily for the comparison of species in the form of clear lumber, are second in importance only to permissible defects [5] in deriving safe working stresses (*8*). Other factors, such as differences in the variability of the clear wood, tendency of defects to develop in service, and tendency to run high or low in the grade, and the like, are, of course, also taken into account in determining working stresses.

Table 2 presents working stresses for a number of common species. Should working stresses be required for other species, they may be derived through the joint use of Tables 1 and 2. The method suggested is to assign to the species under consideration working stresses 10 per cent lower than are given in Table 2 for species having about the same comparative strength values. The 10 per cent reduction is suggested to provide for safety and to allow for the various factors that must be taken into account in assigning safe working stresses. If, however, the species on which working stresses are desired is known to be quite similar in all respects to the species used for comparison, the 10 per cent reduction need not be applied. (See example p. 18.)

EXAMPLES OF GENERAL COMPARISONS

1. Everyone knows how important strength is for shovel handles. Suppose that a manufacturer who has been using ash satisfactorily for shovel handles is offered a supply of hackberry as an alternate. How does hackberry compare with ash? Assuming the most important properties required in a shovel handle to be bending strength, hardness, shock resistance, lightness, and freedom from warping, then from Table 1 the following tabulation may be made:

	Bending strength	Hardness	Shock resistance	Weight (specific gravity)	Volumetric shrinkage
Ash, commercial white	110	108	139	0. 54	126
Hackberry	76	74	145	. 49	138

The lighter weight of hackberry would be an advantage. With the exception of shock resistance, hackberry is decidedly inferior to commercial white ash in the other properties listed. It would not only break more easily in bending, but because of its lower hardness it would also be more subject to mashing at the bolts or rivets. In addition, the slightly higher shrinkage indicates it would not stay in place so well as ash. The conclusion to be drawn from the comparison is not that hackberry is entirely unusable for shovel handles, but rather that average material could not be expected to be as satisfactory as ash.

[5] Tests on structural timbers have established the effect of knots and other defects on strength, and have afforded the basis for preparing structural grades which develop any desired proportion of the strength of the clear wood.

If the inducement is sufficient the user may feel justified in accepting a lower standard of service. By selection methods, however (see p. 15), a wood which averages weaker can frequently be used without lowering the standard of service. If the difference in the average strength of two species is not too great, individual pieces of the weaker species can be obtained which will exceed in strength properties the average of the stronger one. Thus, carefully selected hackberry would make an acceptable shovel handle and one that would be unquestionably better than a handle of poor-quality ash.

This comparison is based on the assumption that the two species would be used in the same sizes. It is possible to make up for certain limitations in the strength of a weaker species of wood by increasing the dimensions of the part. Redesign involving change of size, however, may not always be feasible. In shovel handles the diameter must be such that the handle can be grasped readily. When the usable size is fixed, only species that are strong enough in this size are acceptable. Such practical questions as size must be considered in any change of design or substitution of species.

2. As another example of the practical application of the figures in Table 1, let it be required to compare sugar maple, beech, and yellow birch for flooring. These species are similar in structure in that they all belong to a class known as diffuse-porous woods, which do not have a marked difference in spring wood and summer wood. Among the properties of importance in flooring are shrinkage and hardness. For a comparison of these properties the following figures may be taken from Table 1:

	Radial shrinkage	Tangential shrinkage	Volumetric shrinkage	Hardness
Sugar maple	4. 9	9. 5	147	115
Beech	5. 1	11. 0	162	96
Yellow birch	7. 2	9. 2	166	86

From the figures listed sugar maple, on the average, would be expected to show slightly less change of dimension with given moisture changes than beech or yellow birch, and to offer greater resistance to indentation, wear, and scratching. There is little difference in the volumetric shrinkage figures for beech and yellow birch. Beech, however, averages somewhat higher in hardness.

The comparisons just given do not consider appearance. Since all three species rank relatively high in the physical properties listed, choice may frequently be based on other factors, such as color or price.

3. Just as the figures of Table 1 may be used to select species which are high in certain strength properties, they also serve in choosing the woods to use where ease of manufacture, which is associated with low mechanical properties, is desired. For example, it is generally recognized that wood used to make patterns for metal castings should be readily fashioned to any desired shape and should not change in size. Northern white pine admirably meets these requirements, and has for years been a standard wood for patterns that do not receive such continual use as to require a harder wood. Suppose that because of the scarcity of northern white pine other species are desired. From Table 1 it may be noted that sugar pine and western white pine are much like northern white pine in those

properties which seem to be of first importance, and would, consequently, be among the best species to consider for pattern stock.

4. The preceding examples involve comparisons of species of wood for uses where clear straight-grained material is required. For structural material of grades in which the size, location, and number of defects are limited with reference to their effect on strength by the basic provisions for American lumber standards (*8*), the sizes should be determined and comparisons made as far as possible by means of the safe working stresses of Table 2, Appendix 1, except where these are in conflict with stresses fixed by law. The safe working stresses of Table 2 take into account not only the weakening effect of the defects permitted in the grade, variability, duration of stress, and similar factors, but also the natural chracteristics of the species.

When working stresses or comparisons for structural purposes are desired among species not listed in Table 2, the method suggested on page 16 involving the joint use of Tables 1 and 2 may be applied. Suppose, for instance, that working stresses are desired for lodgepole pine. From Table 1 it may be noted that in bending strength, compressive strength (endwise), stiffness, and hardness, lodgepole pine falls within the range of average values for northern white pine, western white pine, western yellow pine, and sugar pine. For the same grades and conditions of use, therefore, lodgepole pine may be assigned working stresses 10 per cent lower than the values given in Table 2 for northern white pine, without further detailed knowledge of the species. If the fact is known that lodgepole pine is similar to northern white pine in other respects than strength of the clear wood, the 10 per cent reduction in working stresses may be omitted. Hence, if lodgepole pine were included in Table 2, it would be listed with the species which take the same working stresses as northern white pine.

SPECIAL USES

Innumerable comparisons can readily be made from the figures of Table 1. However, there is still another useful type of comparison, namely, that in which several of the different comparative strength properties are combined to give a single figure. This offers an effective way of handling certain problems and has been used in comparing woods for railroad ties and for airplane wing beams, as well as in classifying species for ladder construction. To combine properly the comparative figures of Table 1, however, requires an accurate basic knowledge of the figures, as well as judgment of their relative importance in the proposed use. Because of the complicated nature of these comparisons their further consideration is postponed to Appendix 2.

EXPLANATION OF TABLE 1

(See Table, 1, p. 6.)

COLUMN 1. COMMON AND BOTANICAL NAME OF SPECIES

Column 1 gives the common and botanical names of the various species of wood as adopted by the Forest Service (*7*).

There are a number of closely related species that are very similar in their mechanical properties that can not be distinguished from an examination of the wood alone and that are generally marketed as a group under a single common name, as, for example, commercial white ash. For several such groups the values listed for the individual species comprising the group have been averaged to give a single figure for each property. The species combined are indicated for each group.

COLUMN 2. TREES TESTED

The number of trees tested shows the extent of the work done on each species, and is an aid in estimating the reliability of the average figures. The greater the number of trees tested, the closer may the figures be expected to approach the true average of the species. (See discussion under Variability, p. 14.)

COLUMN 3. SPECIFIC GRAVITY

Specific gravity is the relation of the weight of a substance to that of an equal volume of water. The specific-gravity figures in column 3 are based on the weight of the oven-dry wood and its volume when green.

Column 3 affords an excellent means for making comparisons of the weight of the dry wood of different species. The specific-gravity value gives a direct indication of the amount of wood substance in a given volume.

The weight of oven-dry wood in pounds per cubic foot (based on the volume when green) can be calculated from column 3 by multiplying the specific gravity by 62.4, the weight of water in pounds per cubic foot. The difference between the weight of any oven-dry wood calculated in this manner and the corresponding weight when green is the average weight of moisture present per cubic foot in the unseasoned wood just as it comes from the saw. The moisture present in green wood is of course subject to large variations.

COLUMNS 4 AND 5. WEIGHT PER CUBIC FOOT

Ordinarily, wood is spoken of as "dry" or as "green" or "wet." In order to be specific, various stages of drying or dryness must be recognized in establishing the weight, not only because of the effect of the moisture content on weight, but because of change in volume with moisture changes. The weights of wood at two important stages are given in columns 4 and 5.

When wood is green,[6] or freshly cut, it contains a considerable quantity of water. After wood has dried by exposure to the air until its weight is practically constant, it is said to be "air dry." If dried in an oven at 212° F. until all moisture is driven off, wood is "oven dry."

The weight when green as given in column 4 includes the moisture present at the time the trees were cut, and is based on the average of heartwood and sapwood pieces as represented by test specimens taken from pith to circumference. The moisture content of green timber varies greatly among different species. Thus, in white ash it averages

[6] Green wood usually contains "absorbed" water within the cell walls and "free" water in the cell cavities. In drying, the free water from the cell cavities is the first to be evaporated. The fiber-saturation point is that point at which no water exists in the cell cavities of the timber but at which the cell walls are still saturated with moisture. The fiber-saturation point varies with the species. The ordinary proportion of moisture—based on the weight of the dry wood—at the fiber-saturation point is from 22 to 30 per cent. As a rule, the strength properties of wood begin to increase, and shrinkage begins to occur when the fiber-saturation point is reached in seasoning.

42 per cent, whereas in chestnut it averages 122 per cent.[7] The moisture content also varies among different trees of the same species and among different parts of the same tree. In most softwood species the sapwood has more moisture than the heartwood. For instance, the sapwood of southern yellow pine usually contains moisture in excess of 100 per cent, whereas the heartwood has only about 30 to 40 per cent moisture. Particularly in these species which have a higher moisture content in the sapwood, large variations in weight when green may occur, depending on the proportion of sapwood. Since young softwood trees contain a larger proportion of sapwood than old trees, their wood averages heavier when green.

The amount of moisture in air-dried wood depends on the size and form of the pieces and on the climate. The species vary widely in the rate at which they give off moisture in drying, and also in the rate at which they take up moisture during periods of wet or damp weather. The average air-dry condition reached in the northern Central States in material 2 inches and less in thickness, when sheltered from rain and snow and without artificial heating, is a moisture content of about 12 per cent. The figures given in column 5 are for this moisture content. The moisture content of thoroughly air-dry material may be 3 to 5 per cent higher in humid areas, and in very dry climates, as much lower. Large timbers will have a higher average moisture content when thoroughly air dry than small pieces.

When the moisture content in comparatively dry wood changes, two actions which counteract one another take place, so that the unit weight or weight per cubic foot changes but little. Thus, if the wood dries further, the weight per cubic foot tends to become lower because of loss in moisture, while at the same time it tends to increase because shrinkage causes more wood substance to occupy the same space. Conversely, if wood absorbs moisture both the weight and volume are increased.

An approximate method for estimating the weight of wood per cubic foot at a moisture content near 12 per cent is to regard a one-half per cent change in weight as accompanying a 1 per cent change in moisture content. For example, wood at 8 per cent moisture content weighs about 2 per cent less than at 12 per cent, whereas at 14 per cent moisture content the weight is about 1 per cent greater than at 12 per cent.

COLUMNS 6, 7, AND 8. SHRINKAGE

Shrinkage across the grain (in width and thickness) results when wood loses some of the absorbed moisture.[6] Likewise, swelling occurs when dry or partially dry wood is soaked or when it takes up moisture from the air, similar to a sponge getting larger when wet. Shrinkage of wood in the direction of the grain (length) is usually too small to be of practical importance.[8]

The figures in columns 6 and 7 are average values of the measured radial and tangential shrinkages of small clear specimens in drying from a green to an oven-dry condition. The radial shrinkage is that across the annual growth rings in a cross section, such as in the width

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[6] See footnote 6 on page 19.

[7] The moisture content of wood is commonly expressed as a percentage of the weight of the oven-dry or moisture-free wood. If a specimen from an air-dry board weighed 112 grams immediately after being cut, and after oven drying weighed 100 grams, it is said to have contained 12 per cent moisture. In other words, the moisture content is the original weight minus the oven-dry weight divided by the oven-dry weight, which may be expressed as a percentage by multiplying by 100.

[8] Appreciable longitudinal shrinkage is associated with "compression wood," and other abnormal wood structure. (See p. 31.)

of a quarter-sawed board; the tangential shrinkage is that parallel to the annual-growth rings in a cross section, such as in a flat-sawed board.

Column 8 lists figures on the relative shrinkage in volume from the green to the oven-dry condition for the various species. These figures are computed from actual volume measurements of small clear specimens, combined with actual radial and tangential shrinkage measurements, the results of which are recorded in columns 6 and 7. Volumetric shrinkage values that are comparable with those of columns 6 and 7 may be obtained from column 8 by dividing the figures listed by 10.

The shrinkage which will take place in any piece of wood depends on a great many factors, some of which have not been thoroughly studied. In all species the tangential shrinkage is more than the radial, the average ratio being about 9 to 5. Hence, quarter-sawed (edge-grained) boards shrink less in width but more in thickness than flat-sawed boards. The ratio of radial to tangential shrinkage for a species is of value in determining the desirability of using quarter-sawed wood and indicates the checking which may be expected in large pieces containing pith. Ordinarily, the less the difference between radial and tangential shrinkage, the less is the tendency of such pieces to check in drying.

Air-dry wood is continually taking on and giving off moisture with changing weather or heating conditions. Time is required for these moisture changes, however, so there is always a lag between changes in the humidity of the air and their full effect on the moisture condition of the wood. The lag is greater in some species than in others. As a result some species having a large shrinkage from the green to the oven-dry condition do not cause as much inconvenience in use as woods with lower shrinkage, because they do not follow atmospheric changes so closely. The figures given do not take into account the readiness with which the species take on and give off moisture, and therefore should be considered as the relative shrinkage between woods after long exposure to fairly uniform atmospheric conditions or after the same change in moisture content.

COLUMN 9. BENDING STRENGTH

Column 9 gives figures on bending strength. Bending strength is a measure of the load-carrying capacity of beams, which are usually horizontal members resting on two supports. Examples of members subjected to bending are stadium seats, scaffold platforms, ladder steps, shovel handles, girders, bridge stringers, and floor joists. The figures for bending strength afford a direct comparison of the breaking strength of clear wood of the various species. They may also be used under certain conditions for comparing structural material in which defects are limited with reference to their effect on strength. (See p. 16.)

Bending strength in addition to other properties is essential in many uses, such as airplane-wing beams or spars, telephone and telegraph poles, mine lagging, railway ties, ladder side rails, pike poles, insulator pins, and wagon tongues. It is of less importance in studding, flooring, and subflooring.

If a species is low in bending strength it does not necessarily follow that it is unsuited for uses requiring this property. It does indicate, however, that larger sizes are required to carry given loads than are required for species which rank higher in this property.

COLUMN 10. COMPRESSIVE STRENGTH (ENDWISE)

The figures of column 10, compressive strength, apply to comparatively short compression members. Compression members are generally square or circular in cross section, usually upright, supporting loads which act in the direction of the length. The loads tend to shorten the piece. Some examples of endwise-compression members are upright members in grand stands, mine props, vertical pieces which support girders in buildings, and vertical scaffold frame pieces.

When compression members are of a length about 11 times the least dimension, the slenderness has increased to such an extent that stiffness begins to be a factor in the strength. The quantities in column 10 are applicable to short columns having a ratio of length to least dimension of 11 (or less) to 1.

If one species is lower in compressive strength than another, the difference may be compensated by using a member of correspondingly larger cross-sectional area.

COLUMN 11. STIFFNESS

When any weight or load is placed on a member, a deflection is produced. Stiffness is a measure of the resistance to deflection and relates particularly to beams. It is one of the properties required in ladder side rails, golf shafts, floor joists, girders, rafters, and other beams as well as in long columns. The figures in column 11 give the average stiffness of the different species. Generally beams of species having high stiffness values deflect less under a load than the same sized beams of species having lower stiffness values. Difference in stiffness between species may be compensated by changing the size of members.

COLUMN 12. HARDNESS

Hardness is the property which makes a surface difficult to dent or scratch. The harder the wood, other things being equal, the better it resists wear, the less it crushes or mashes under loads, and the better it can be polished; on the other hand, the more difficult it is to cut with tools, the harder it is to nail and the more it splits in nailing. Hardness is desirable in such uses as flooring, furniture, railroad ties, and small handles. Some lack of hardness, that is, a degree of softness, is particularly desirable for uses such as drawing boards. The greater the figure given in the table, the greater the hardness of the wood.

There is a pronounced difference in hardness between the spring wood and the summer wood of some species, such as southern yellow pine and Douglas fir. In these species the summer wood is the denser, darker-colored portion of the annual growth ring. In such woods differences in surface hardness occur at close intervals on a piece, depending on whether spring wood or summer wood is encountered. In woods like maple, which do not have pronounced spring wood and summer wood, the hardness of the surface is more nearly uniform.

COLUMN 13. SHOCK RESISTANCE

Shock resistance is the capacity to withstand suddenly applied loads. Hence, woods high in shock resistance withstand repeated shocks, jars, jolts, and blows such as are given ax handles, wheel spokes, and golf shafts. Hickory possesses this shock resistance property to the highest degree of any of the common and well-known woods. The greater the figure in column 13, the greater is the shock resistance of the species.

PERCENTAGE ESTIMATED PROBABLE VARIATION

The percentage figures in the bottom two lines of Table 1, exclusive of footnotes, offer a means of estimating the variability, a detailed discussion of which is given in the Appendix 3.

The percentage figures in the last line of Table 1 indicate the variation, above and below the average, which may be expected to include half of all the material of a species. For example, consider the bending strength of red alder in Table 1. The bending strength (column 9) is 76, and the variation of an individual piece is 12 per cent. From these figures it may be estimated that the bending strength of one-half of the red alder would fall within the limits 67 and 85. The approximate proportion of material of a species falling within certain other percentages of the Table 1 values may be estimated on the basis of the following relations:

75 per cent is within 1.71 times the percentage probable variation.
82 per cent is within 2.00 times the percentage probable variation.
90 per cent is within 2.44 times the percentage probable variation.
96 per cent is within 3.00 times the percentage probable variation.

The percentage figures in the next to the last line indicate that there is an even chance that the true average is within these percentages of the figures in Table 1. The percentages given apply to species which are represented by five trees. Percentages applying to species represented by various numbers of trees from 1 to 50 are presented in Table 6.

Mortality statistics upon which insurance rates are based tell very closely how many men of any large group will live to be a certain age, but they do not enable one to say whether John Doe at that age will be included among the living. In a similar manner, the variability figures given in the next to the last line of Table 1 permit one to estimate how many of the species of wood will have their averages raised or lowered by a specified amount by additional tests, but one can not say that red alder or any other designated species will be raised by this amount.

APPENDIX 1

For the aid of engineers, architects, and others who desire additional information on the application and derivation of the figures in Table 1 the following information is given. A study of the three appendixes is not essential for the use of Table 1 for comparative purposes.

STRENGTH OF STRUCTURAL MATERIAL

The figures in Table 1 are most directly applicable to the comparison of species for uses requiring wood free from defects. For structural material of grades in which the size, location, and number of defects are limited with reference to their effect on strength, the relative strengths of the species are better represented by allowable working stresses used in design. Working stresses for select and common structural grades conforming to the basic provisions of the American lumber standards are given in Table 2. They are technical in nature and have been arrived at from a consideration of the strength and variability of the clear wood, the relation of density to strength, the effect of defects in structural sizes, the effect of long-continued loading, and the inherent characteristics of the species, such as prevalence of knot clusters, tendency to check in seasoning, and prevalence of shakes. The figures in Table 1 are the average results of tests on clear wood of the different species; those of Table 2 are assigned values, based not only on tests, but on experience and judgment.

TABLE 2.—*Working stresses for timber conforming to the basic provisions for select and common structural material of American lumber standards* [1]

[As recommended by the Forest Products Laboratory, Forest Service, United States Department of Agriculture]

Species	Fiber stress in bending [2]									
	Continuously dry		Occasionally wet but quickly dried				More or less continuously damp or wet			
	All thicknesses		Material 4 inches and thinner		Material 5 inches and thicker		Material 4 inches and thinner		Material 5 inches and thicker	
	Select grade	Common grade	Select grade	Common grade	Select grade	Common grade	Select grade	Common grade	Select grade	Common grade
	Lbs. per sq. in.	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*
Ash, black	1,000	800	800	680	900	720	710	600	800	640
Ash, commercial white	1,400	1,120	1,070	910	1,200	960	890	760	1,000	800
Aspen and largetooth aspen	800	640	580	490	650	520	440	370	500	400
Basswood	800	640	580	490	650	520	440	370	500	400
Beech	1,500	1,200	1,150	980	1,300	1,040	890	760	1,000	800
Birch, paper	900	720	670	570	750	600	530	450	600	480
Birch, yellow and sweet	1,500	1,200	1,150	980	1,300	1,040	890	760	1,000	800
Cedar, Alaska	1,100	880	890	760	1,000	800	800	680	900	720
Cedar, western red	900	720	710	600	800	640	670	570	750	600
Cedar, northern and southern white	750	600	580	490	650	520	530	450	600	480
Cedar, Port Orford	1,100	880	890	760	1,000	800	800	680	900	720
Chestnut	950	760	760	650	850	680	620	530	700	560
Cottonwood, eastern and black	800	640	580	490	650	520	530	450	600	480
Cypress, southern	1,300	1,040	980	830	1,100	880	800	680	900	720
Douglas fir (western Washington and Oregon type) [3]	1,600	1,200	1,233	983	1,387	1,040	948	756	1,067	800
Douglas fir (dense) [3]	1,750	1,400	1,349	1,147	1,517	1,213	1,037	882	1,167	933
Douglas fir (Rocky Mountain type)	1,100	880	800	680	900	720	620	530	700	560
Elm, rock	1,500	1,200	1,150	980	1,300	1,040	890	760	1,000	800
Elm, slippery and American	1,100	880	800	680	900	720	710	600	800	640
Fir, balsam	900	720	670	570	750	600	530	450	600	480
Fir, commercial white	1,100	880	800	680	900	720	710	600	800	640
Gum, red, black, and tupelo	1,100	880	800	680	900	720	710	600	800	640
Hemlock, eastern	1,100	880	800	680	900	720	710	600	800	640
Hemlock, western	1,300	1,040	980	830	1,100	880	800	680	900	720
Hickory (true and pecan)	1,900	1,520	1,330	1,130	1,500	1,200	1,070	910	1,200	960

Larch, western	1,200	960	980	830	1,100	880	800	680	900	720
Maple, sugar and black	1,509	1,200	1,150	980	1,300	1,040	890	760	1,000	800
Maple, red and silver	1,000	800	800	680	900	720	620	530	700	560
Oak, commercial red and white	1,400	1,120	1,070	910	1,200	960	890	760	1,000	800
Pine, southern yellow [3]		1,200		983		1,040		756		800
Pine, southern yellow (dense) [3]	1,750	1,400	1,349	1,147	1,517	1,213	1,037	882	1,167	933
Pine, northern white, western white, western yellow, and sugar	900	720	710	600	800	640	670	570	750	600
Pine, Norway	1,100	880	890	760	1,000	800	710	600	800	640
Poplar, yellow	1,000	800	800	680	900	720	710	600	800	640
Redwood	1,200	960	890	760	1,000	800	710	600	800	640
Spruce, red, white, and Sitka	1,100	880	800	680	900	720	710	600	800	640
Spruce, Engelmann	750	600	580	490	650	520	440	370	500	400
Sycamore	1,100	880	800	680	900	720	710	600	800	640
Tamarack (eastern)	1,200	960	980	830	1,100	880	800	680	900	720

[1] American lumber standards: Basic provisions for American lumber standards grades are published by the United States Department of Commerce in Simplified Practice Recommendation No. 16, Lumber, revised July 1, 1926; specifications for grades conforming to American lumber standards are published in the 1927 Standards of the Amer. Soc. for Testing Materials, and in Amer. Ry. Engineering Assoc. Bul., vol. 30, No. 314, dated February, 1929.

[2] Stress in tension: The working stresses recommended for fiber stress in bending may be safely used for tension parallel to grain.

[3] Exact figures given: In order to preserve the exact numerical relations among working stresses for grades involving rate of growth and density requirements the values for Douglas fir (western Washington and Oregon type) and for southern yellow pine have not been rounded off, as have the values for the other species.

TABLE 2.—*Working stresses for timber conforming to the basic provisions for select and common structural material of American lumber standards*—Continued

Species	Compression perpendicular to grain, select and common grades			Horizontal shear [4]		Compression parallel to grain (short columns having ratio of length to least dimension of 11 or less)						Average modulus of elasticity [5]
	Continuously dry	Occasionally wet but quickly dried	More or less continuously damp or wet	Not varied with conditions of exposure		Continuously dry		Occasionally wet but quickly dried		More or less continuously damp or wet		Not varied with conditions of exposure or with grade
				Select grade	Common grade	Select grade	Common grade	Select grade	Common grade	Select grade	Common grade	
	Lbs. per sq. in.	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*
Ash, black	300	200	150	90	72	650	520	550	440	500	400	1,100,000
Ash, commercial white	500	375	300	125	100	1,100	880	1,000	800	900	720	1,500,000
Aspen and largetooth aspen	150	125	100	80	64	700	560	550	440	450	360	900,000
Basswood	150	125	100	80	64	700	560	550	440	450	360	900,000
Beech	500	375	300	125	100	1,200	960	1,100	880	900	720	1,600,000
Birch, paper	200	150	100	80	64	650	520	550	440	450	360	1,000,000
Birch, yellow and sweet	500	375	300	125	100	1,200	960	1,100	880	900	720	1,600,000
Cedar, Alaska	250	200	150	90	72	800	640	750	600	650	520	1,200,000
Cedar, western red	200	150	125	80	64	700	560	700	560	650	520	1,000,000
Cedar, northern and southern white	175	140	100	70	56	550	440	500	400	450	360	800,000
Cedar, Port Orford	250	200	150	90	72	900	720	825	660	750	600	1,200,000
Chestnut	300	200	150	90	72	800	640	700	560	600	480	1,000,000
Cottonwood, eastern and black	150	125	100	80	64	700	560	550	440	450	360	900,000
Cypress, southern	350	250	225	100	80	1,100	880	1,000	800	800	640	1,200,000
Douglas fir (western Washington and Oregon type) [5]	[6] 347	[6] 240	[6] 213	90	72	1,173	880	1,067	800	907	680	1,600,000
Douglas fir (dense) [3]	379	262	233	105	84	1,283	1,027	1,167	933	992	793	1,600,000
Douglas fir (Rocky Mountain type)	275	225	200	85	68	800	640	800	640	700	560	1,200,000
Elm, rock	500	375	300	125	100	1,200	960	1,100	880	900	720	1,300,000
Elm, slippery and American	250	175	125	100	80	800	640	750	600	650	520	1,200,000
Fir, balsam	150	125	100	70	56	700	560	600	480	500	400	1,000,000
Fir, commercial white	300	225	200	70	56	700	560	700	560	600	480	1,100,000
Gum, red, black, and tupelo	300	200	150	100	80	800	640	750	600	650	520	1,200,000
Hemlock, eastern	300	225	200	70	56	700	560	700	560	600	480	1,100,000
Hemlock, western	300	225	200	75	60	900	720	900	720	800	640	1,400,000
Hickory (true and pecan)	600	400	350	140	112	1,500	1,200	1,200	960	1,000	800	1,800,000

Larch, western	325	225	200	100	80	1,100	880	1,000	800	800	640	1,300,000
Maple, sugar and black	500	375	300	125	100	1,200	960	1,100	880	900	720	1,600,000
Maple, red and silver	350	250	200	100	80	800	640	700	560	600	480	1,100,000
Oak, commercial red and white	500	375	300	125	100	1,000	800	900	720	800	640	1,500,000
Pine, southern yellow [3]	(6)	(6)	(6)	----------	88	----------	880	----------	800	----------	680	1,600,000
Pine, southern yellow (dense) [3]	379	262	233	128	103	1,283	1,027	1,167	933	992	793	1,600,000
Pine, northern white, western white, western yellow, and sugar	250	150	125	85	68	750	600	750	600	650	520	1,000,000
Pine, Norway	300	175	150	85	68	800	640	800	640	700	560	1,200,000
Poplar, yellow	250	150	125	80	64	800	640	700	560	600	480	1,100,000
Redwood	250	150	125	70	56	1,000	800	900	720	750	600	1,200,000
Spruce, red, white, and Sitka	250	150	125	85	68	800	640	750	600	650	520	1,200,000
Spruce, Engelmann	175	140	100	70	56	600	480	550	440	450	360	800,000
Sycamore	300	200	150	80	64	800	640	750	600	650	520	1,200,000
Tamarack (eastern)	300	225	200	95	76	1,000	800	900	720	800	640	1,300,000

[3] Exact figures given: In order to preserve the exact numerical relations among working stresses for grades involving rate of growth and density requirements the values for Douglas fir (western Washington and Oregon type) and for southern yellow pine have not been rounded off, as have the values for the other species.

[4] Joint details: The shearing stresses for joint details may be taken for any grades as 50 per cent greater than the horizontal shear values for the Select grade.

[5] Factors to be applied to average modulus of elasticity values: The values for modulus of elasticity are average for species and not safe working stresses. They may be used as given for computing average deflection of beams. When it is desired to prevent sag in beams values one-half those given should be used. In figuring safe loads for long columns values one-third those given should be used.

[6] Working stresses for the Common grade: The values given are for the Select grade. Working stresses in compression perpendicular to grain for the common grades of Douglas fir (western Washington and Oregon type) and southern yellow pine are 325, 225, and 200, respectively, for continuously dry, occasionally wet but quickly dried, and more or less continuously damp or wet conditions.

Since moisture influences the strength and the durability of wood, certain of the allowable working stresses are varied with the moisture conditions to which the timber will be exposed. All of the values in any one vertical column of Table 2 are on the same basis, and comparison of species may be made for the specified conditions of use. Allowable working stresses also depend on the grade of timber, as determined by the size and location of defects. The figures in Table 2 apply to timber conforming to the basic provisions of American lumber standards for select and common structural material (*2*, *8*).

EXPLANATION OF TABLE 2

(See Table 2, p. 24)

The following explanation of the values given in Table 2 may be of aid in their use:

Fiber stress in bending is a measure of the bending strength and is proportional to the load which can be carried by a beam of a given size. It is the same kind of strength measure as "Bending strength," as defined on page 21.

Compression perpendicular to grain is a measure of the bearing strength of wood across the grain. The surfaces of contact between a floor joist and a girder in a building are in compression perpendicular to grain. A high value in this property indicates that large loads across the grain can be supported without injury to the wood.

Horizontal shear is a measure of the capacity of a beam to resist slipping of the upper half upon the lower along the grain. This property becomes of great importance in beams whose depth is more than about one-twelfth the distance between supports.

Compression parallel to grain is a measure of the capacity of a short column to withstand loads acting in the direction of the length. It is similar to compressive strength (endwise) described on page 22. As the ratio of length to least dimension exceeds 11, the column becomes more slender and the capacity to carry end loads becomes more and more dependent upon stiffness until in long columns a length is reached where modulus of elasticity (stiffness) determines the load-carrying ability. The values given are consequently not applicable to columns in which the ratio of length to least dimension exceeds 11 to 1.

Modulus of elasticity is a measure of the stiffness or rigidity of a material. It indicates the resistance of a beam to deflection. It measures the same property as stiffness, described on page 22. The higher the modulus of elasticity, the less will be the deflection under a given load.

Working stresses for design will also be found in the report of the building code committee (*10*) and in standards of the American Society for Testing Materials (*2*).

APPENDIX 2

METHOD OF COMPUTING COMPARATIVE STRENGTH AND SHRINKAGE FIGURES IN TABLE 1

There is a need for a system of simplified strength figures for wood whereby comparisons may be made by the average wood user without employing highly technical terms. To supply this need the Forest Products Laboratory has developed a method of combining various test results into five composite strength values [9] for which data are given in Table 1. Any method of combining data must involve considerable judgment and must be somewhat empirical; consequently, differences of opinion may exist as to the best procedure. This appendix presents the method used in deriving the composite figures presented in Table 1.

The method involves (1) determining what properties should be combined in each composite figure; (2) reducing the values which have been obtained in different tests and which may be in various units to a common basis; (3) weighting the individual properties according to their estimated relative importance; and (4) weighting and combining the composite values for green and air-dry material in a single composite figure.

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[9] These five strength values are bending strength, compressive strength (endwise), stiffness, hardness, and shock resistance.

PROPERTIES STUDIED

The fundamental data used as a basis for establishing the comparative figures were obtained from a comprehensive study begun by the Forest Service in 1910 to determine certain mechanical properties of woods grown in the United States (*4*). Data on 25 or more different properties were obtained from standard tests (*1*) on small clear specimens of both green and air-dry wood. These properties, listed under the standard tests used for determining them, are as follows:

1. Compression parallel to grain:
   - Fiber stress at elastic limit.
   - Maximum crushing strength.
   - Modulus of elasticity.
2. Static bending:
   - Fiber stress at elastic limit.
   - Modulus of rupture.
   - Modulus of elasticity.
   - Work to elastic limit.
   - Work to maximum load.
   - Total work.
3. Impact bending:
   - Fiber stress at elastic limit.
   - Modulus of elasticity.
   - Work to elastic limit.
   - Height of drop of hammer causing complete failure.
4. Compression perpendicular to grain:
   - Fiber stress at elastic limit.
5. Hardness (load required to imbed a ball 0.444 inch in diameter to one-half its diameter):
   - Side grain (radial; tangential).
   - End surface.
6. Shear parallel to grain:
   - Shear stress (radial; tangential).
7. Cleavage:
   - Load per inch of width (radial; tangential).
8. Tension perpendicular to grain:
   - Tensile stress (radial; tangential).
9. Tension parallel to grain:
   - Tensile stress.
10. Shrinkage:
    - Radial.
    - Tangential.
    - Volumetric.
11. Specific gravity.

In several instances two or more of these tests yield data on the same property. For example, modulus of elasticity (stiffness) values are obtained from three different tests. Likewise hardness is indicated by both the compression perpendicular to grain and hardness tests. Bending strength is indicated by fiber stress at elastic limit in impact bending and by fiber stress at elastic limit and modulus of rupture in static bending. The comparative figures (Table 1) are the result of combining the values for each group of similar properties. However, several of the properties just listed were not used in determining the figures in Table 1.

REDUCTION FACTORS

On account of the differences in the nature, significance, and magnitude of these related test results they should not be combined by a direct average. Combining such properties as work to maximum load and total work in static bending (inch-pounds per cubic inch) and height of drop in impact bending (inches), therefore, can best be done by first applying "reduction factors" to adjust the properties to a common basis. Numerical values of the reduction factors were established from formulas expressing the relation of each property to specific gravity. The specific gravity-strength relations determined from the average data for different species are given in Table 3. The equations as tabulated have recently been reestablished on the basis of all available data and for this reason differ somewhat from those previously published (*5*).

TABLE 3.—*Specific gravity-strength relations* [1]

Property	Unit	Moisture condition	
		Green	Air dry (12 per cent moisture content)
Static bending:			
Fiber stress at elastic limit	Pounds per square inch	$10200G^{1.25}$	$16700G^{1.25}$
Modulus of rupture	do	$17600G^{1.25}$	$25700G^{1.25}$
Work to maximum load	Inch-pounds per cubic inch	$35.6G^{1.75}$	$32.4G^{1.75}$
Total work	do	$103G^{2}$	$72.7G^{2}$
Modulus of elasticity	1,000 pounds per square inch	$2360G$	$2800G$
Impact bending:			
Fiber stress at elastic limit	Pounds per square inch	$23700G^{1.25}$	$31200G^{1.25}$
Modulus of elasticity	1,000 pounds per square inch	$2940G$	$3380G$
Height of drop	Inches	$114G^{1.75}$	$94.6G^{1.75}$
Compression parallel to grain:			
Fiber stress at elastic limit	Pounds per square inch	$5250G$	$8750G$
Maximum crushing strength	do	$6730G$	$12200G$
Modulus of elasticity	1,000 pounds per square inch	$2910G$	$3380G$
Compression perpendicular to grain:			
Fiber stress at elastic limit	Pounds per square inch	$3000G^{2.25}$	$4630G^{2.25}$
Hardness:			
End	Pounds	$3740G^{2.25}$	$4800G^{2.25}$
Radial	do	$3380G^{2.25}$	$3720G^{2.25}$
Tangential	do	$3460G^{2.25}$	$3820G^{2.25}$

[1] The values listed in this table are to be read as equations, for example: Modulus of rupture for green material $=17600G^{1.25}$, where G represents the specific gravity, oven dry, based on volume at moisture condition indicated.

For shock resistance the basis to which all component properties are adjusted is work to maximum load in static bending. Consequently, the reduction factor for work to maximum load is unity. The reduction factor for height of drop in impact bending is determined by its average relation to work to maximum load. For green material, the reduction factor is

$$\frac{35.6G^{1.75}}{114G^{1.75}}=0.31$$ [10]

The reduction factor for total work in static bending is likewise determined by its average relation to work to maximum load, and for green material is

$$\frac{35.6G^{1.75}}{103G^{2}}=0.41$$ [10]

when $G=0.50$. Reduction factors applicable to the values for air-dry material were established in the same manner.

Unity reduction factors were used for each of the three determinations of modulus of elasticity in arriving at the composite stiffness figure, rather than the equation relations, since the modulus of elasticity values are all measures of the same property and are in like units.

WEIGHTING FACTORS

In combining the mechanical properties into comparative strength figures, weighting factors were applied according to the estimated relative importance of the properties entering into the combination. In bending strength, for example, modulus of rupture was given a weight of 2 as compared to each of the fiber stresses at elastic-limit values because of the greater importance of the modulus of rupture, and because the determinations of the elastic limit from curves are subject to the personal equation.

Table 4 lists the mechanical properties which enter into the composition of each comparative figure, together with the corresponding reduction and weighting factors.

[10] When the equations of properties to be combined involve different exponents, the reduction factor obtainable varies with the specific gravity (G). In such cases the reduction factor used corresponds to a specific gravity of 0.50, this being approximately the average specific gravity of all species tested.

TABLE 4.—*Properties combined and reduction and weighting factors used in deriving comparative figures*

Property	Reduction factor: Green	Reduction factor: Air-dry at 12 per cent moisture	Weighting factor
Bending strength:			
Fiber stress at elastic limit, static bending	1.72	1.54	1
Modulus of rupture, static bending	1.00	1.00	2
Fiber stress at elastic limit, impact bending	.74	.82	1
Compressive strength (endwise):			
Fiber stress at elastic limit, compression parallel to grain	[1] 2.82	[1] 2.52	1
Maximum crushing strength, compression parallel to grain	[1] 2.20	[1] 1.805	2
Stiffness:			
Modulus of elasticity, static bending	1.00	1.00	2
Modulus of elasticity, impact bending	1.00	1.00	1
Modulus of elasticity, compression parallel to grain	1.00	1.00	1
Hardness:			
Fiber stress at elastic limit, compression perpendicular to grain	1.00	1.00	2
End hardness, hardness test	.80	.96	1
Radial hardness, hardness test	.89	1.24	1
Tangential hardness, hardness test	.87	1.21	1
Shock resistance:			
Work to maximum load, static bending	1.00	1.00	2
Total work, static bending	.41	.52	1
Height of drop, impact bending	.31	.34	2
Volumetric shrinkage:			
Radial plus tangential shrinkage (green to oven-dry)	[2] 1.00	------------	1
Volumetric shrinkage (green to oven-dry)	[2] 1.00	------------	2

[1] The reduction factors for compressive strength translate the values into terms of modulus of rupture so that the resulting values can be combined directly with "bending strength" to give a joint figure representing "bending or compressive strength" (formerly called "strength as a beam or post"). To get "bending or compressive strength" give "bending strength" a weight of 4 and "compressive strength (endwise)" a weight of 3.

[2] Apply to values which represent shrinkage from the green to the oven-dry condition.

In calculating the comparative strength values the average test results for each species were used. The comparative values for green material (A) and for air-dry material (B) were separately calculated and were then combined as follows:

$$\frac{2A+B}{3}=\text{comparative strength value (bending strength, etc.),}$$

where A = value as calculated from averages for green material,
B = value as calculated from averages for air-dry material (12 per cent moisture).

It may be noted that the averages for green material were multiplied by 2 and those for air-dry material by 1 in arriving at the comparative strength values. This gives the figures for green material an apparent weight of 2, but in reality they receive an actual weight somewhere between 1 and 2 because no reduction factor was used to bring the figures for air-dry material to the same magnitude as those for green material. However, the averages for green material were intentionally given a somewhat greater weight than those from the air-dry because a larger number of tests are included.

The final comparative figure, therefore, does not represent either green or dry material, but approximates a condition of 20 per cent moisture content. The calculated results are indicated to only two or three significant figures in Table 1 and have, consequently, lost their identity as far as stress units are concerned. As tabulated, they are in effect index numbers.

SAMPLE CALCULATION

The following example will illustrate in detail the calculation method:

(1) Required, the "bending strength" value for red alder (*Alnus rubra*).

(2) Given, the following average values (*4*) for the species, in pounds per square inch:

	Green	Air-dry
Fiber stress at elastic limit, static bending	3,800	7,100
Modulus of rupture, static bending	6,500	10,000
Fiber stress at elastic limit, impact bending	8,000	11,700

[1] Adjusted to 12 per cent moisture.

(3) Calculation for green material (A):

	Strength value		Reduction factor		Weighting factor		Product
Fiber stress at elastic limit, static bending	3, 800	×	1. 72	×	1	=	6, 540
Modulus of rupture, static bending	6, 500	×	1. 00	×	2	=	13, 000
Fiber stress at elastic limit, impact bending	8, 000	×	0. 74	×	1	=	5, 920
Total					4		25, 460
Value for green material			25, 460	÷	4	=	6, 365 = A

(4) Calculation for air-dry material (12 per cent moisture content) (B)

	Strength value		Reduction factor		Weighting factor		Product
Fiber stress at elastic limit, static bending	7, 100	×	1. 54	×	1	=	10, 930
Modulus of rupture, static bending	10, 000	×	1. 00	×	2	=	20, 000
Fiber stress at elastic limit, impact bending	11, 700	×	0. 82	×	1	=	9, 594
Total					4		40, 524
Value for air-dry material (12 per cent moisture content)			40, 524	÷	4	=	10, 131 = B

(5) Bending strength $=\frac{2A+B}{3}=\frac{(2\times 6365)+10131}{3}=7620.$

The "bending-strength" values as calculated by the foregoing formula were divided by 100 before entering them in Table 1. This gives the value 76 for red alder, which agrees with the table.

The procedure for deriving the other comparative strength properties from the original data is similar.

SHRINKAGE IN VOLUME

The comparative shrinkage in volume figures (column 8, Table 1) were calculated according to the following formula:

$$\text{Volumetric shrinkage}=\frac{R+T+2V}{3}$$

where R = average radial shrinkage,
T = average tangential shrinkage,
V = average volumetric shrinkage.

The volumetric shrinkage values as calculated by the foregoing formula were multiplied by 10 before being entered in column 8 of Table 1.

Radial and tangential shrinkage measurements were made on specimens 1 inch thick by 4 inches wide by 1 inch long, and shrinkage in volume measurements on specimens 2 by 2 inches in cross section by 6 inches long.

LIMITATIONS

There are certain limitations to the use of comparative strength figures or index numbers because the individual basic properties are masked. Therefore, when the data on individual basic properties can be more logically applied than the comparative strength values, they should be used in preference (*4*).

Another possible limitation of the comparative strength figures is that they represent neither green nor thoroughly air-dry material. In most instances practically the same comparisons would result if figures from green material only or from air-dry material only were combined. This will not be true, however, if a species is exceptional in its moisture-strength relations. Redwood, one of the common commercial species, is such an example, being very high in strength for its density when green and increasing less in strength with seasoning than most other woods. Comparisons from Table 1 will give such species too low a rating for a use in which the material will remain wet and too high for a use requiring dry stock. The comparative figures, except shrinkage, may be considered to represent material at about 20 per cent moisture content for bending strength, compressive strength, stiffness, and hardness. Shock resistance is not affected greatly by moisture changes, but usually incurs a slight loss rather than a gain with decrease in moisture.

In spite of such limitations, the comparative values are useful for many types of comparisons. Whether comparative strength values or basic strength properties should be used is a matter of judgment.

SPECIAL USES OF COMPARATIVE FIGURES

RAILROAD TIES

As illustrative of the special uses referred to on page 18, let it be required to sum into a single figure for each species the mechanical properties of most importance in railroad ties. Knowledge of the properties involved and their relative importance must be available (*9*) or assumed before attempting to arrive at such a figure. In ties bending strength is required to resist bending; compressive strength (endwise) to resist rail thrust against spikes; and hardness to resist rail cutting and mechanical wear. A method which has been used for combining these figures to obtain strength figures for crossties, in which hardness is given equal importance with bending strength and compressive strength combined (see footnote 1, Table 4), is as follows:

Multiply the value given in Table 1 for bending strength by 4, that for compressive strength by 3, and that for hardness by 7. Add these products and divide by 14 to get the final number. This may be expressed by the formula:

$$\text{Tie strength figure} = \frac{4D+3E+7F}{14}$$

where D = bending strength (column 9, Table 1),
E = compressive strength (column 10, Table 1),
F = hardness (column 12, Table 1).

The strength figure for a chestnut crosstie, as calculated by this method, is 59; that for white oak, 104; from which it is seen that white oak, as is well known, is the better as far as strength is concerned. Other factors must, of course, be taken into account in selecting woods for ties, especially resistance to decay. This again calls for judgment and experience in evaluating the relative importance of durability (resistance to decay) and strength, in accordance with service conditions.

AIRPLANE WING BEAMS

The comparative strength values were used by the Forest Products Laboratory as a guide for appraising the relative suitability of the different species for airplane wing beams. The properties considered were specific gravity, bending and compressive strength, stiffness, and shock resistance. The weights given each of these properties were as follows:

	Weight
Bending and compressive strength (combined)	1
Stiffness	1
Shock resistance	1. 5

The values for bending and compressive strength, stiffness, and shock resistance were first expressed as ratios of the corresponding values for spruce, which was taken as the basis of comparisons. These ratios were then weighted as just shown and averaged. This average was divided by the specific-gravity ratio raised to the $3/2$ power to get the final index of suitability.

In this analysis the consideration of such factors as influence of size on the strength, stiffness, and buckling of thin parts, together with the essential requirement in aircraft of keeping weight to a minimum, necessitated that a power of the specific gravity be used. Here, again, judgment was called for in the proper selection and weighting of the factors involved.

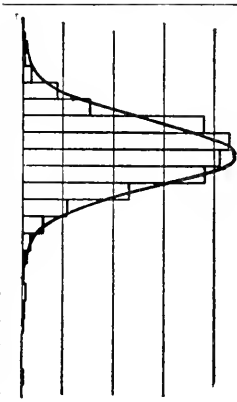
A somewhat similar system of analysis was used in classifying species in the development of the safety code for ladder construction. The data of Table 1 offer opportunity for many other types of analyses and comparisons, limited only by the judgment employed in their use.

APPENDIX 3

SIGNIFICANCE OF VARIABILITY

Brief reference has been made on page 14 to the variability of wood and other materials. It is important to know that wood is variable, but it is more important to know something of the nature and extent of this variability. The range of variability can be illustrated and better understood by considering the results of specific gravity determinations on 2,105 separate pieces of Sitka spruce which have been studied at the Forest Products Laboratory. These specific-gravity values are presented in Table 5, which lists the highest and lowest observed results, together with the number of pieces in different groups.

TABLE 5.—*Results of specific gravity determinations on 2,105 samples of Sitka spruce*

Specific gravity[1] group limits	Pieces in group		Variability diagram (number of specimens in group) 0 100 200 300 400
	Number	*Per cent*	
0.220 to 0.239	1	0.05	
.240 to .259	3	.14	
.260 to .279	18	.86	
.280 to .299	70	3.33	
.300 to .319	133	6.32	
.320 to .339	359	17.05	
.340 to .359	411	19.53	
.360 to .379	392	18.62	
.380 to .399	345	16.39	
.400 to .419	211	10.02	
.420 to .439	91	4.32	
.440 to .459	43	2.04	
.460 to .479	16	.76	
.480 to .499	3	.14	
.500 to .579	1	.05	
.520 to .539	4	.19	
.540 to .559	2	.09	
.560 to .579	1	.05	
.580 to .599	0	.00	
.600 to .619	0	.00	
.620 to .639	1	.05	

[1] Specific gravity oven-dry based on volume when green.
Average specific gravity equals 0.364; highest observed specific gravity 0.626; lowest 0.236.

It may be noted that the specific gravity of the heaviest piece[11] included in the series was two and two-third times that of the lightest, and that the number of very heavy and very light pieces is quite small. Most of the values are grouped quite closely about the average.

The manner is which the samples tend to group themselves about the average is called a frequency distribution, from which the chances of departure from the average can be estimated by computation. Such a calculation, assuming a so-called normal distribution and representative material, leads to the expectation that one-half of the Sitka spruce samples would be within less than 7.5 per cent of the average specific gravity, or between the limits 0.337 and 0.391, and that approximately only one-fourth would be below 0.337 and one-fourth above 0.391. The figure defining such limits, 7.5 per cent in this case, is called the probable variation. By actual count, 51.7 per cent of the pieces studied (1,089) have a specific gravity between 0.337 and 0.391, whereas that of 24.8 per cent (522) was below 0.337 and that of 23.5 per cent (494) was above 0.391. As might be

[11] The exceptionally heavy pieces of Sitka spruce result from an abnormal growth called compression wood frequently occurring in the underside of leaning trees and limbs. Compression wood also forms in other softwood species, and, unlike normal wood, it has a large endwise or longitudinal shrinkage which causes warping and twisting when it occurs in the same piece with wood of normal growth. Longitudinal shrinkage as high as 2½ per cent has been observed in compression wood, whereas the longitudinal shrinkage of normal wood is a small fraction of 1 per cent. Compression wood is very dense and includes what appears to be an excessive summer-wood growth. Compression wood in most species shows but little contrast in color between spring wood and summer wood. Large differences in weight from causes other than compression wood are also found. Thus, in certain softwood species some pieces are increased in weight because of the resinous materials they contain, while in some hardwoods, such as tupelo and ash, unusually lightweight wood is formed in the swelled butts of swamp-grown trees.

expected, the percentages determined by actual count do not agree exactly with the foregoing calculated percentages, but the agreement is sufficiently close to show the value of the theory in estimating the variability even when a normal distribution is assumed. The frequency distribution of the specific gravity values for these 2,105 samples of Sitka spruce is shown as a diagram in the last column in Table 5.

The figures in Table 1 are each based on tests of a number of pieces, some of which were above and some below the average, just as with the specific gravity of Sitka spruce. In using wood of any species one may desire to know the proportion of material within a given range in any property or to know the probable amount the averages may be changed by additional tests. After tests have been made it is of course easy from the results to determine the proportion of the test pieces which were within any given range, but one can only estimate the degree to which this test data applies to other specimens and to the reliability of the averages. In other words, one would like to know the true average values of each species, a quantity which can not actually be obtained. The best that can be done is to consider the laws of chance operative and thus estimate the probable variation which may be expected from given average values. Such is the basis of the suggestions and estimates of variability presented in Table 1 and Appendix 3.

It would be desirable to present the variation of each property of each species as determined from the detailed data. However, the extensive calculations involving all properties and species have not been completed; and even if available, their presentation would be more involved than the nature of this bulletin warrants. Although it is known that all species are not exactly equal in variability, it is felt that they are enough alike so that estimates made on the assumption of an equal percentage variability for all species in a given property will be sufficient for most practical purposes.

PROBABLE VARIATION

EXPLANATION OF FIGURES

The variability of each property is indicated by the probable variation figures in the last two lines at the bottom of Table 1. In the next to the last line is given the estimated probable variation of the observed species average from the true species average. The value listed applies only when the observed average is based on tests from five trees.[12] The values for other numbers of trees may be obtained from Table 6. In the last line of Table 1 is given the estimated probable

[12] The method of calculating the variation of an individual tree is as follows:

$$\sigma^2=\frac{\Sigma\left(\frac{a-\bar{a}}{\bar{a}}\right)^2+\Sigma\left(\frac{b-\bar{b}}{\bar{b}}\right)^2+\Sigma\left(\frac{c-\bar{c}}{\bar{c}}\right)^2+\ldots}{n_a+n_b+n_c+\ldots}$$

where $\Sigma\left(\frac{a-\bar{a}}{\bar{a}}\right)^2=\left(\frac{a_1-\bar{a}}{\bar{a}}\right)^2+\left(\frac{a_2-\bar{a}}{\bar{a}}\right)^2+\left(\frac{a_3-\bar{a}}{\bar{a}}\right)^2\ldots$

$a_1, a_2, a_3 \ldots$ being averages for specimens from each of the n_a trees (usually 5) of species-locality a and

$$\bar{a}=\frac{a_1+a_2+a_3\ldots}{na}$$

$b_1, c_1, b_2, c_2, \bar{b}, \bar{c}, n_b, n_c \ldots$ being similarly defined.

It may be seen that σ as thus defined is not the usual root-mean-square deviation but is somewhat analogous to the coefficient of variation. It is in fact the weighted root-mean-square value of coefficient of variation as obtained from a number of samples. This may be seen by writing the above formula in the equivalent form:

$$\sigma^2=\frac{n_a\left(\frac{\sigma_a}{\bar{a}}\right)^2+n_b\left(\frac{\sigma_b}{\bar{b}}\right)^2+n_c\left(\frac{\sigma_c}{\bar{c}}\right)^2+\ldots}{n_a+n_b+n_c+\ldots}$$

Correcting for size of sample, $\sigma'=\frac{\sigma}{0.8407}$ (6), 0.8407 being used because the modal value is 5. Probable variation = $0.6745\,\sigma'$.

variation of an individual piece[13] from the true average. The probable variation of 8 per cent for the specific gravity of an individual piece indicates that there is an even chance that a random specimen will fall within 8 per cent (above or below) of the average, and an even chance that it will differ more than 8 per cent from the average. To illustrate, suppose that the hardness of red alder is under consideration. The probable variation in hardness for an individual piece is found from Table 1 to be 16 per cent. Taking the hardness of red alder as 48, the hardness of one-half of the pieces will, on the average, fall between the values 40.3 and 55.7, while approximately one-fourth would be below 40.3 and one-fourth above 55.7. The greater the probable variation, the greater the difference that may be expected in values, and the less the certainty with which the average figures can be applied to individual pieces.

PROBABLE CHANGES IN OBSERVED AVERAGE

The extent of the probable change in the observed average for the different properties should be considered in comparing species. The estimated probable variation in the observed average of the species, when based on different numbers of trees, is given in Table 6.

TABLE 6.—*Percentage probable variation [1] of the observed average from the true average of the species, when based on material from different numbers of trees*

Number of trees	Specific gravity	Shrinkage			Bending strength	Compressive strength (endwise)	Stiffness	Hardness	Shock resistance
		Radial	Tangential	Volumetric					
1	4.7	11.6	9.0	8.8	5.5	7.3	7.2	6.3	11.1
2	3.3	8.2	6.4	6.2	3.9	5.2	5.1	4.5	7.9
3	2.7	6.7	5.2	5.1	3.2	4.2	4.2	3.6	6.4
4	2.4	5.8	4.5	4.4	2.8	3.6	3.6	3.2	5.6
5	2.1	5.2	4.0	3.9	2.5	3.3	3.2	2.8	5.0
10	1.5	3.7	2.8	2.8	1.7	2.3	2.3	2.0	3.5
15	1.2	3.0	2.3	2.3	1.4	1.9	1.9	1.6	2.9
20	1.0	2.6	2.0	2.0	1.2	1.6	1.6	1.4	2.5
30	0.9	2.1	1.6	1.6	1.0	1.3	1.3	1.2	2.0
40	0.7	1.8	1.4	1.4	0.9	1.2	1.1	1.0	1.8
50	0.7	1.6	1.3	1.2	0.8	1.0	1.0	0.9	1.6

[1] The percentage probable variation of the average of the species is a figure such that there is an even chance that the true average is within this percentage of the observed average in Table 1.

The average is always the most probable value. Occasionally the variation may be much larger than indicated, but the probability of occurrence of a variation decreases rapidly as the magnitude of the variation increases.

The importance of the differences between species with respect to averages is dependent on the magnitude of this difference in relation to the probable variation of the averages, as well as on how exacting the strength requirements are for the particular use under consideration .

HOW TO ESTIMATE THE SIGNIFICANCE OF DIFFERENCES IN THE AVERAGE PROPERTIES OF TABLE 1

If the averages of any property of two species (Table 1) differ by an amount equal to the probable variation of the difference,[14] there is one chance in four that

[13] Estimated for each component property by combining the corrected probable variation of a tree, and the probable variation of an individual specimen from the tree, according to the usual method The probable variation of composite figures was calculated by combining the probable variation of component properties, assuming first, complete independence of properties, and second, complete correlation of properties. The correlation coefficient of component properties was found to approach unity (0.90 between fiber stress at elastic limit in compression parallel to grain and maximum crushing strength; 0.92 between fiber stress at elastic limit in impact bending and modulus of rupture in static bending). Values of probable variation for composite figures presented in Table 1 are estimated from calculations just referred to, and those of the last line, Table 1 further compared with calculations of probable variation of an individual piece from the species averages for a limited number of species. It is hoped that ultimately such calculations will be made with the data on all species.

[14] The probable variation of the difference of two average figures is the square root of the sum of the squares of the probable variations of the averages. The probable variation of the average of any property may be estimated from the figures in Table 6. For an example, see page 37.

the true average for the species which is lower in that property on the basis of present data equals or exceeds the true average of the other. There is also one chance in four that the true average for the higher species exceeds that of the lower one by as much as twice the observed difference. When the averages differ by amounts which are 1, 2, 3, 4, or 5 times the probable variation of their difference, the chances of the true average of the lower species equaling or exceeding the true average of the higher, or of the observed difference being at least doubled are as follows:

TABLE 7.—*Chance that if the true average were available the order would be reversed, or the true difference found to be at least twice as great as the observed, when the observed difference is 1, 2, 3, 4, or 5 multiples of the probable variation of the difference*

Multiples	Chance	Multiples	Chance
1	1 in 4.	4	1 in 285.
2	1 in 11.	5	1 in 2,850.
3	1 in 46.		

As an example, consider the figures for bending strength of 60 and 62 for black and eastern cottonwood, respectively (Table 1). These figures are based on five trees of each species. From Table 6 or the next to the last line of Table 1, the probable variation of the species when based on five trees is 2.5 per cent of the bending strength. Two and five-tenths per cent of 60 equals 1.50, and 2.5 per cent of 62 equals 1.55, the probable variations of these averages. The probable variation of the difference between the averages is then $\sqrt{(1.50)^2 + (1.55)^2}$ or 2.16; the observed difference in the average figures for bending strength (60 and 62) is 2, which is less than its probable variation, 2.16. The chance that the true average bending strength for black cottonwood equals or exceeds that for eastern cottonwood is approximately one in four. There is the same chance that the true average of eastern cottonwood exceeds that for black cottonwood by at least 4 (twice the difference in present average figures as shown in Table 1). Hence, the difference between the figures for black and eastern cottonwood with respect to bending strength is not important for most practical purposes.

As a second example, consider the figures for bending strength of 117 and 106 for sweet birch and yellow birch, respectively. (Table 1.) The figures for sweet birch are based on 10 trees, those for yellow birch on 17. From Table 6 the probable variation of the species average when based on 10 trees is 1.7 per cent and when based on 17 trees it is 1.3 per cent. (The figure for 17 trees is taken as midway between that given for 15 trees and 20 trees.) The probable variation in bending strength of sweet birch is 1.7 per cent of 117, or 1.99; of yellow birch is 1.3 per cent of 106, or 1.38. The probable variation of the difference between the averages is $\sqrt{(1.99)^2+(1.38)^2}$ or 2.42. The difference between the observed averages (117 and 106) is 11, which is about four and one-half times its probable variation of 2.42. From Table 7 it may be estimated that the chances are only one in more than 285 that the true average for bending strength of yellow birch would equal or excel that for sweet birch. The importance of such differences will depend on the use to be made of the wood.

Calculations of probable variation as suggested above should not be taken too literally but should rather be regarded as estimates.

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THE WESTERN GRASS-STEM SAWFLY[1] A PEST OF SMALL GRAINS

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INTRODUCTION

The western grass-stem sawfly (*Cephus cinctus* Norton) (fig. 1) is in many ways one of the most interesting and important insects that has attracted the special attention of the economic entomologists in the last 20 years. It is a species native to the United States and has been gradually coming into prominence since the beginning of the present century by reason of the change in its larval feeding habits since its discovery. Originally a grass feeder, it is becoming a serious menace in the Northwestern States because of its acquired appetite for small grains, within the stems of which it now subsists. Such changes of diet are probably occurring everywhere with greater frequency than formerly was deemed possible, especially among the phytophagous insects of the Middle West. When given a chance to feed upon the various cultivated plants grown in bulk by the farmer or gardener, many of these insects gradually desert their native host plants and to a greater or less degree change their habits, including in their fare the more succulent and easily found food.

HISTORY

The existence of the western grass-stem sawfly was first made known in 1890 when Albert Koebele reared adults from larvae that were mining in the stems of native grass growing in the vicinity of Alameda, Calif.[2] In 1891 the species was described under the

[1] This bulletin is a revision of and supersedes Department Bulletin No. 841, The Western Grass-Stem Sawfly, issued May 7, 1920.

[2] KOEBELE, A. CALIFORNIA NOTES. U. S. Dept. Agr., Div. Ent. Insect Life 3: 71, 1891.

name of *Cephus occidentalis* by Riley and Marlatt,[3] from a series of individuals reared by Mr. Koebele and also from cotypes that had in the meantime been collected in Nevada and Montana. In connection with this description the following prophetic suggestion was made:

> The economic importance of this species arises from the fact that it may be expected at any time to abandon its natural food-plant in favor of small grains, on which it can doubtless successfully develop.

Nothing more was heard of this sawfly until 1895, when James Fletcher, then entomologist of the Dominion of Canada, swept adults at Indian Head, Northwest Territories, on July 5. He believed it to belong to the European species *Cephus pygmaeus* L., and under this name it was mentioned in his report for 1896[4] with the further

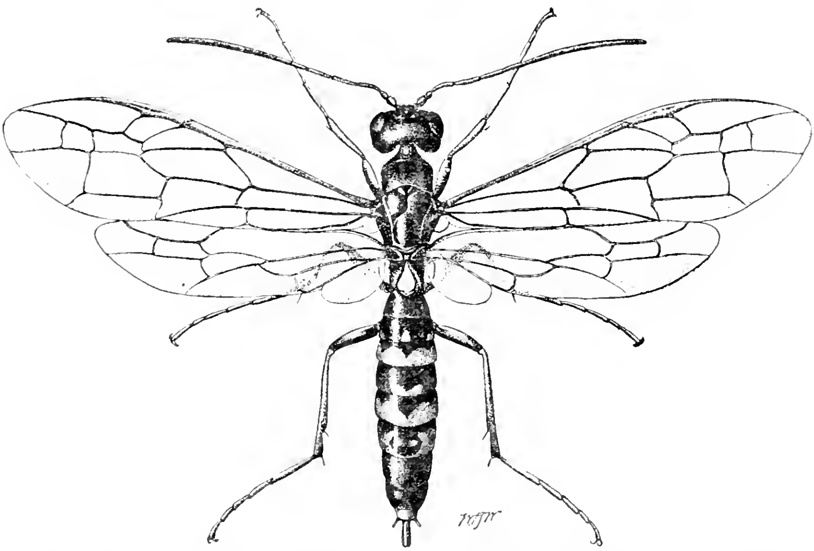

FIGURE 1.—Adult female of western grass-stem sawfly (*Cephus cinctus*). Enlarged to about 1½ or 5 diameters

statement that wheat straws containing Cephus larvae had been sent in by John Wenman, of Souris, Manitoba, who stated that the injury done by them was very slight. Nevertheless the prophecy of five years before had been fulfilled, since these grass feeders actually had attacked small grain.

In 1902 Fletcher reported, in a personal letter, that he had found the larvae numerous in grasses in the Northwest. In 1905 and 1906 G. I. Reeves, of the Bureau of Entomology, noted the work of the larvae in various grasses, chiefly *Agropyron* sp., in Wyoming and the Dakotas, and in 1906 the same observer found the larvae attacking wheat sparingly near Kulm, N. Dak.

On August 31, 1907, E. G. Kelly noted a few wheat straws near Minot, N. Dak., that had been burrowed by the larvae of Cephus.

[3] RILEY, C. V., and MARLATT, C. L. WHEAT AND GRASS SAWFLIES. U. S. Dept. Agr., Div. Ent. Insect Life 4: 177–178, illus., 1892.

[4] FLETCHER, J. REPORT OF THE ENTOMOLOGIST AND BOTANIST. Canada Expt. Farms Rpt. 1896: 229–230, illus. 1897.

In 1908 F. M. Webster and G. I. Reeves found the larvae of Cephus working in grasses in the Willamette Valley in Oregon. In the same year Fletcher again called attention to this insect, stating that in the previous fall it had appeared in central Manitoba and in the southeastern part of Saskatchewan in much more serious numbers than ever before, and that the quantity of broken straws in the fields was causing the farmers some alarm. Norman Criddle of Aweme, Manitoba, a close observer and practical farmer, wrote to Fletcher that this fly had increased considerably during the last year or two, and was turning its attention to wheat and rye.

On August 20, 1909, H. B. Penhallow reported from Sherwood, N. Dak., that he had examined about a hundred fields from Minot, N. Dak., north to the boundary line and several miles into Canada and had found larvae present in every field but one. He estimated the damage in these fields as ranging from 5 to 25 per cent of the

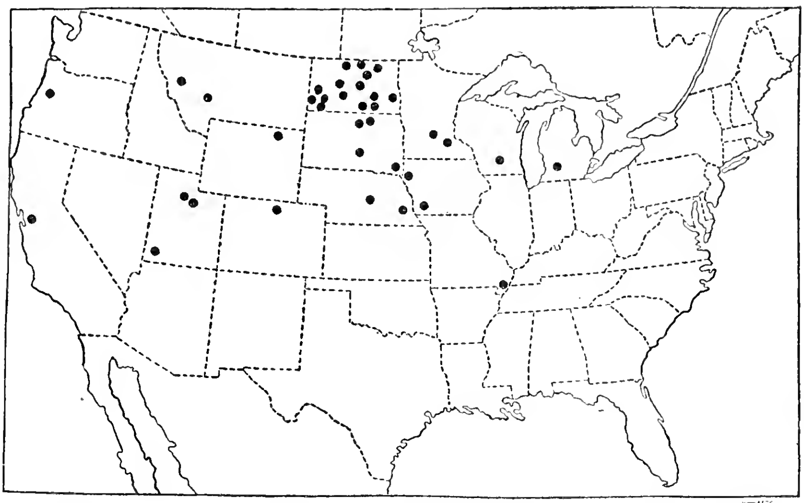

FIGURE 2.—Distribution of the western grass-stem sawfly in the United States

crop, but spoke of one field about 27 miles east of Sherwood where the damage was said to have exceeded 66 per cent. R. W. Sharpe reported similar damage in the Red River Valley, near Fargo, N. Dak.

During 1911 and 1912 the writer found the species occurring freely in the native grasses in various parts of Utah, and, as occasion offered, the life history of Cephus was learned. Many of the facts in this bulletin are the result of this study. (Fig. 3.)

During the years 1913, 1914, and 1915 the writer found this sawfly almost universally distributed over the Dakotas, Minnesota, Iowa, and Nebraska. It was feeding in Elymus, timothy, and Agropyron at Elk Point, S. Dak., in *Agropyron tenerum* near Chamberlain, S. Dak., in timothy at Edgeley, N. Dak., in *Bromus inermis* near Merricourt, N. Dak., in *Elymus canadensis* at Shakopee, Minn., in practically all these grasses near Sioux City, Iowa, and in wheat, timothy, and Elymus near Minot, N. Dak.

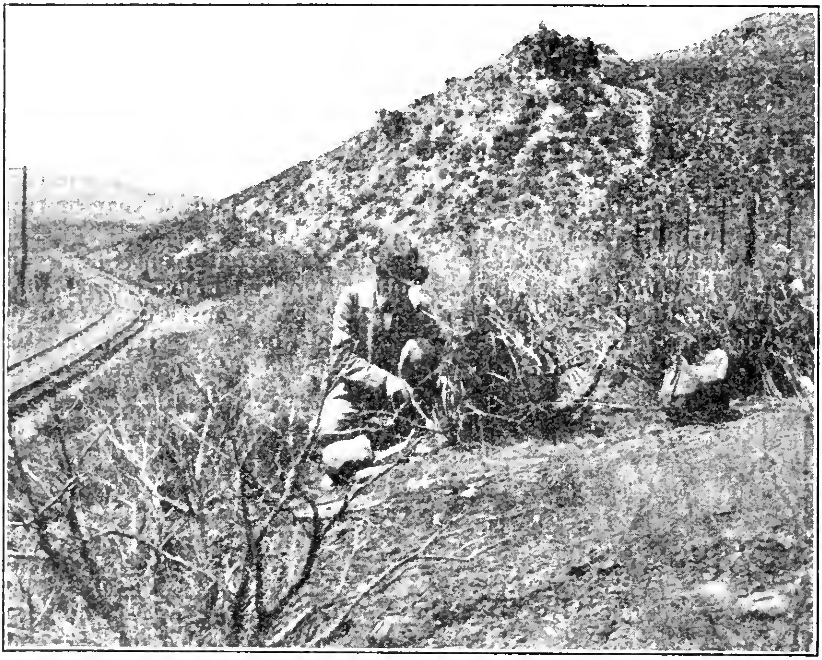

FIGURE 3.—Plants of *Elymus condensatus* growing along the railroad right of way, the natural habitat of the western grass-stem sawfly in Utah

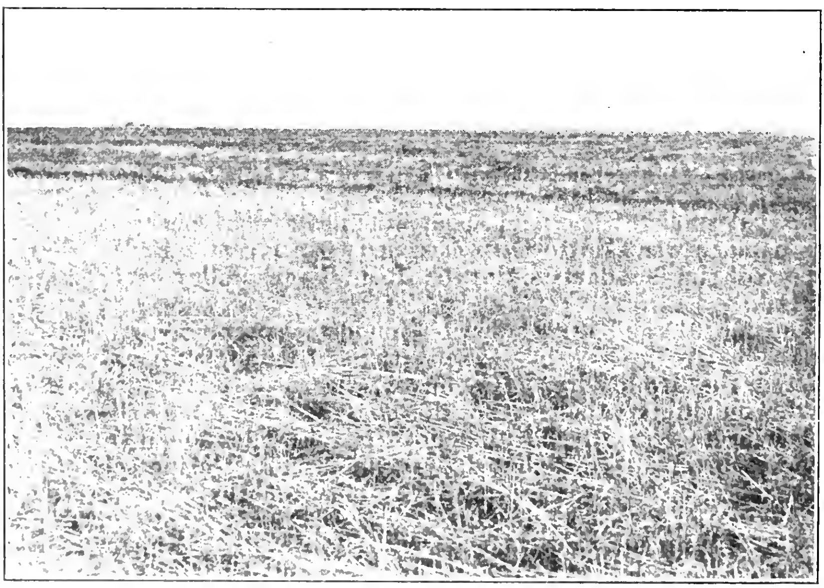

FIGURE 4.—Wheatfield of Thomas Yeam, near Souris, N. Dak., showing heavy damage done by the western grass-stem sawfly in 1916

This insect seems to have little choice in the various native grasses and is ready to attack any of the cultivated sorts provided the stem is sufficiently large for the larval gallery. As a rule, the larger, more robust stems are chosen for attack, especially in cultivated grasses such as timothy and Bromus. Bluegrass and similar slender-stemmed species appear to be immune. *Stipa viridula* from northern New Mexico, a robust grass growing in almost the same latitude as the *Elymus condensatus* near Pinto, Utah, where the fly abounds, was not found infested.

August 25, 1916, the writer, then at Pierre, S. Dak., received instructions from the Bureau of Entomology to visit Bottineau County

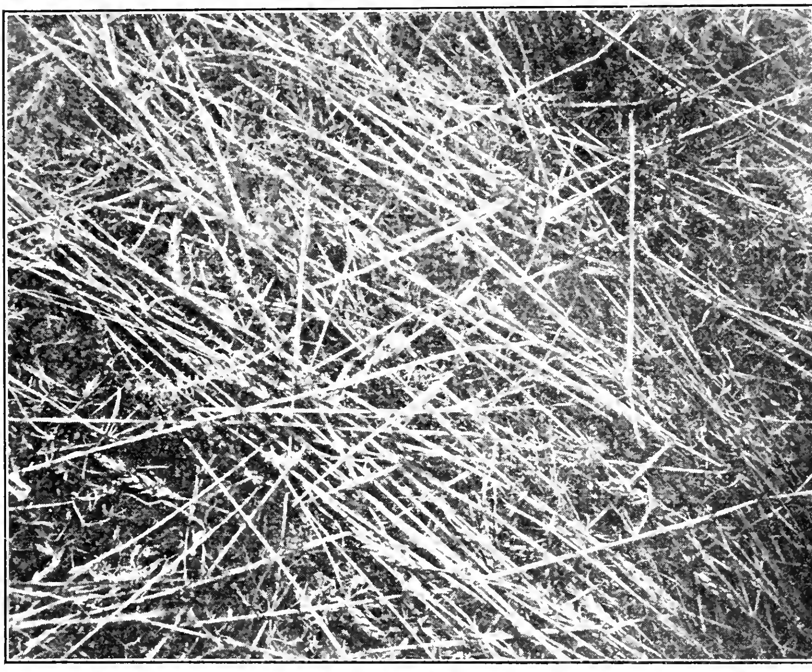

FIGURE 5.—Bird's-eye view of wheat in Thomas Yeam's field, near Souris, N. Dak. Ninety per cent of these fallen wheat stems have been mined by the western grass-stem sawfly

in North Dakota and investigate injury to wheat. It was believed locally that the Hessian fly was responsible for the damage that was being done. A very superficial examination of the injured fields proved beyond a doubt that the Cephus was present in large numbers and was doing an immense amount of mischief. Every field visited was infested, not only in Bottineau County, but in the adjoining counties of Benson, Pierce, McHenry, and Rolette. Near Souris, a few miles south of the Canada line, a large field of wheat on the farm of Thomas Yeam was fairly carpeted with the "straw-fallen" grain. (Figs. 4 and 5.) The loss from injury by Cephus in this field was estimated at 60 per cent or more. Six feet of drill row here was taken at random and examined plant by plant. Forty-eight infested stubs were found, an average of eight to each foot of drill row. This would mean 150 to the square yard or about 726,000 larvae to the acre. Higher counts were made later in the same field, so the average may be larger than stated. During April, 1917, Mr. Yeam's field was again visited and a random square yard marked out and counted. Two hundred and sixty-nine infested stubs were taken from this yard, which would mean more than 1,300,000 larvae to the acre. Fifty of these stubs were opened and 47 of the imprisoned larvae that had spent the winter within the straw were found to be normal and very much alive. The proportion of living individuals among the hibernating larvae seldom falls below this ratio.

In the spring of 1917 the dry weather in this district hindered the growth of both grasses and grains, so when the adult Cephus began to appear in June there was almost no opportunity for oviposition. Stems of Bromus from chance sods growing among wheat and on waste ground were filled with eggs. Young plants of spring wheat that had barely begun to joint were attacked and often contained as many as three and four eggs placed in the stem close to the ground. With a few strokes of the net 136 adults were swept from young wheat, so numerous were the flies at that time. In spite of the unfavorable oviposition conditions of that spring, the eggs appear to have hatched, and at harvest time the majority of the wheat stems had been bored and many were cut off at the base. Careful harvesting and the use of horserakes saved a large portion of what otherwise would have been a total loss. The infestation was much more general than in 1916.

A somewhat hasty reconnaissance was made through north-central North Dakota in August, 1919, that it might be ascertained as definitely as possible just how the attack of Cephus was progressing. A number of fields in Bottineau County were examined and found to be heavily infested. Most of these had been raked after harvest, and it was consequently impossible to compute accurately the percentage of infestation. The numerous sawfly inhabited stubs in the drill rows, however, proved the severity of the attack. It was roughly, though conservatively, estimated that about 30 per cent of the grain had gone down in most of these fields as the result of Cephus work.

It was conceded by many observers in that region that the injury during the year 1919 was greater than during any previous year since the study of this pest was begun. More fields had been seriously invaded and were injured to a larger extent than had before been observed. Even fields of durum wheat, hitherto believed to be nearly free from fly attack, were said to have been severely injured in 1919.

It may be stated, however, that the farmers are profiting by past experience and have used horserakes to gather the fallen grain in stubble fields to such an extent that the percentage of actual loss of grain has been reduced to a small figure. The quality of grain from the fallen straw is naturally somewhat below the normal, since the work of the larvae in the stems produces some injury in the heads as they fill.

Cephus was found mining wheat near Hettinger in southwestern North Dakota, July 18, 1917. On September 22, 1917, infested wheat was found near Mott, 30 miles north of Hettinger. In October of the same year many wheatfields in Towner and Cavalier Counties, in northeastern North Dakota, showed heavy infestation, although during the previous year it was difficult to discover more than a trace of the presence of Cephus in the wheat in this region.

Sods of *Elymus canadensis* sent to the writer from Charleston, Mo., in the summer of 1917 contained at least one larva of *Cephus cinctus* that had been boring the stem of this grass in that region.

From the map (fig. 2) and foregoing brief summary of its history it may be seen that *Cephus cinctus* is distributed over an immense territory and that it constitutes a potential menace to the small grains throughout this vast region. As the acreage of native grasses is decreased from year to year by the bringing of wild lands under the plow, pests such as the sawfly will be forced to depend in an increasingly large measure upon the small grains and other products of the farms. On this account the injury caused by these formerly harmless insects bids fair to increase steadily. In the past the numbers of grass-feeding insects such as the one considered in this bulletin have been governed mainly by the supply of food plants. A dry summer that retarded the growth of long-stemmed grasses would automatically reduce the numbers of the insects that lived within these grass stems. It is easy to see how seasonal fluctuations in vegetation would, to a large extent, react either to multiply or diminish the numbers of these insects. Cephus seems to defy the drought.

Then again, the farmer, by introducing fields of grain into a region previously uncultivated, brings in conditions unknown before and invites the attack of these and other formerly harmless insects, making it possible for them to become a menace to his future.

A somewhat similar sawfly of European origin[5] was discovered in 1918 to have become established on wheat along the Atlantic seaboard from Long Island southward to northern Virginia.

FOOD PLANTS

The various species of Agropyron and Elymus, genera both of which are well represented in the West, appear to have been the original hosts of the larvae. Since the feeding habits of the insect have been modified by changing agricultural conditions, the list of their present host plants, so far as known, stands as follows:

Elymus canadensis.	*Agropyron occidentale.*	*Calamagrostis* spp.
Elymus condensatus.	*Agropyron caninum.*	*Festuca* sp.
Agropyron tenerum	*Hordeum jubatum.*	Wheat.
Agropyron richardsoni.	*Bromus inermis.*	Barley.
Agropyron smithii.	*Phleum pratense.*	Spelt.
Agropyron repens.	*Deschampsia* sp.	Rye.

Since the larva is wholly unable to move from one stem to another, it is very obvious that the host stem must be large enough to afford both shelter and food during its entire growing period. Hence only the larger-stemmed grasses can serve as host plants for the Cephus larvae. Occasionally an unusually vigorous plant of a slender-

[5] *Trachelus tabidus* (Fab.). See the following publication: GAHAN, A. B., BLACK GRAIN-STEM SAWFLY OF EUROPE IN THE UNITED STATES. U. S. Dept. Agr. Bul. 834, 18 p., illus. 1920.

stemmed grass, like *Hordeum jubatum*, affords stalks with diameter sufficiently great to be attacked by Cephus.

Small grains, such as wheat and rye, readily serve as hosts to this insect, because they are of suitable size and the length of their growing season coincides with the growth of the larva. Even if harvest time should happen to come before the maturity of the larva, the reaping machine probably would sever the stem far enough above the ground to leave the larva below the sickle cut, where it could house itself safely before the end of the season.

DISTRIBUTION

Up to the present time this species has confined itself almost entirely to the West and has been found in only a few localities east of the Mississippi River, namely, in Wisconsin and Michigan. West of the Mississippi River it has been recorded from Minnesota, Iowa, Missouri, North Dakota, South Dakota, Nebraska, Montana, Wyoming, Colorado, Utah, Nevada, Oregon, and California. Its choice of wheat for food has taken place, so far as known, only in North Dakota, Montana, and western Canada.

THE EGG

The egg of *Cephus cinctus* is, when newly laid, decidedly crescent-shaped, glassy in appearance, milky white, usually quite symmetrical, the ends of the crescent tapering and rounded. It is marked by very faint, short, longitudinal lines or wrinkles, placed without regard to order or pattern.

The size of the egg varies with the size of the female that produced it and measures from 1 to 1.25 mm. in length. The greatest breadth is about one-third the length.

The covering membrane is hyaline and transparent. Although very thin and delicate it is strong enough for the egg to be safely lifted and moved by the aid of a fine brush. The egg always lies free within the stem of the host plant, either in the stem cavity or in a hollow excavated by the ovipositor of the female. This cell is always a little larger than the egg, so it is comparatively an easy matter to remove the egg to a moist cell or elsewhere for study.

The number of eggs laid by each female appears to vary but little. Dissections of a number of adults taken in the field and of others reared in captivity agree in most cases in giving a count of about 50 eggs in the ovaries, these eggs being, as a rule, equal in size and apparent maturity.

After a number of trials it was found to be impracticable to rear the egg in situ, since it was next to impossible to maintain the proper moisture conditions within the stem. The method that was finally adopted, and that gave excellent results, was to remove the egg from the stem and place it in a minute drop of water within a small thin watch glass which was then immediately inverted on a glass slip and sealed with a ring of water to prevent undue evaporation. This form of moist cell proved quite satisfactory and permitted continuous examination of the egg with a moderately high-power lens during the entire period of incubation. It was found necessary, in order to conserve the requisite moisture supply during a period of several days, to invert over the sealed cell a larger watch glass and over this in turn a tumbler. In this manner evaporation was reduced to a minimum. It is altogether probable that the quantity of moisture in such a protected cell exceeded that normally present within the grass stem, but in every egg treated in this way the development appeared to progress naturally.

Temperature and moisture are the prime factors that hasten or retard egg development. The temperature maintained within the laboratory during the course of these investigations was much more equable than that in the field, where, as in Utah, the heat of the sun through the daytime, and the chilly night following, must alternately hasten and check development. The data given below, therefore, may only approximate what is actually found under field conditions.

A few hours after the egg leaves the oviduct the milky-white contents of the egg, which at first completely fill the envelope, shrink a little from each end, leaving a transparent space or vacuole. After the first day the egg changes shape, becomes intumescent, generally loses its crescent shape entirely, and grows oval or reniform in outline. Gradually the interior mass of exceedingly minute particles coalesces until about the second day when a series of faintly discernible cells arranging themselves along a central axis begins to appear. Early on the third day the form of the larva can be dimly seen, the head being almost transparent and filling one end of the egg sac. The body is looped on itself, the cauda folded beneath the abdomen and extending forward nearly to the head. By the close of the third day the abdominal segments are usually well defined.

During the fourth day, in most cases, a spasmodic and intermittent heart beat may be noticed. These pulsations become more and more regular as the hours pass, and during the fifth and sixth days the heart beats with much regularity at the rate of about 120 impulses per minute. At intervals it may be retarded to 75 beats, but it soon resumes its former rate.

The head appears disproportionately large at this time, but although its general outlines are well defined the mandibles and eye spots are not yet visible. Overnight, at the close of the fifth day, the mandibles turn brown and the eye spots appear and darken. Usually after the fourth day the muscular system of the larva is in almost constant motion, shifting and adjusting, with the heart pulsating and the muscles moving, all clearly to be seen through the transparent membrane that serves as the shell.

The activity of the larva within the sac increases during the sixth day and either on this day or the seventh it escapes from its confinement by a series of convulsive movements that rupture the delicate shell and set it free.

THE LARVA

When it escapes from the egg the larva (fig. 6) possesses a very large head armed with a pair of powerful biting jaws and has a vigorous appetite. It is very active from the start and begins almost at once to feed upon the living parenchymatous tissue by which it is surrounded in the interior of the stem, excavating for itself a threadlike gallery both above and below the cavity where the egg formerly lay.

The larva is nearly transparent and colorless until it become filled with the tissue on which it subsists.

The body segments are strongly and clearly marked from the time the larva leaves the egg. The mandibles are brown, three or four pointed, the points chisel-shaped, beveled on the inside edge. The brown face plate is filled with crossed bands of striated muscular fiber that actuate the powerful jaws. The caudal horn, by means of which the larva moves up and down in its gallery, is also brown and is armed, even in the first instar, with a series of stout bristles at the base of its cylindrical and squarely truncate extremity. The larva is footless, the position of the legs being marked by minute, rounded tubercles terminating in a few short bristles.

Although the primary excavation made by the larva may extend for a short distance above the egg cell, the general course of the progress is invariably downward. In its earlier stages of existence, at least, the larva traverses its gallery several times, swallowing repeatedly the same fragments of tissue that have already been devoured during the first excavation of the stem. Young larvae are frequently found several inches above the lower end of the boring, moving through the solidly packed "sawdust." As the larva approaches maturity it is doubtful if it ventures into the upper and slender part of the stem, but it reworks the frass farther down, enlarging the bore in places.

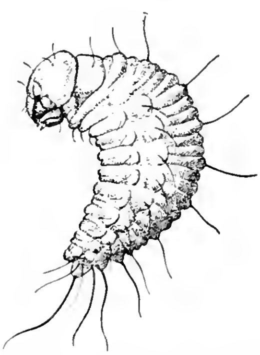

FIGURE 6.—Newly hatched larva of western grass-stem sawfly. Enlarged about 20 diameters

The number of instars is difficult to determine, owing to the larval practice, just referred to, of passing all the frass several times through the digestive apparatus. Nearly all of the cast skins disappear completely under this treatment, only the heavily chitinized parts such as the mandibles and caudal horn being recognizable in the burrow. Careful investigation of these fragmentary remains indicates that there are four or more molts. The contents of innumerable stems have been examined with scrupulous care and with varying results. In a few cases as many as four sets of mandibles and in others four caudal horns have been found, mixed with the frass within the stems. Seldom were more than four sets removed from a single stem; usually only three were found. As is stated elsewhere in this bulletin, it is no uncommon thing to discover two and even three larvae mining a single stem, although only a single individual can possibly reach maturity with the quantity of nutriment contained in one stem. It is believed that the larva that finally reaches maturity has devoured its rivals. It is obvious that the remains of these superfluous individuals would naturally be counted when a census of exuviae was undertaken and would complicate the result. But from the best evidence obtainable it is almost certain that there are five instars in the larval life of this species.

The length of the larval period is probably about 60 days, varying more or less with the warmth of the summer and the state of maturity of the host stems. Any change of the oviposition period due to an early or late spring has much to do with the date of maturity of the larvae, and possibly with the length of the larval period. On August 29, 1911, at Kimballs, Utah, at an elevation of 7,000 feet, the writer found mature larvae in the stems of *Elymus condensatus*. The next year, at the same place, oviposition was beginning freely in the first week of July. The determination of the larval period is wholly inferential, based upon the findings in a series of stems. (Figs. 7 and 8.)

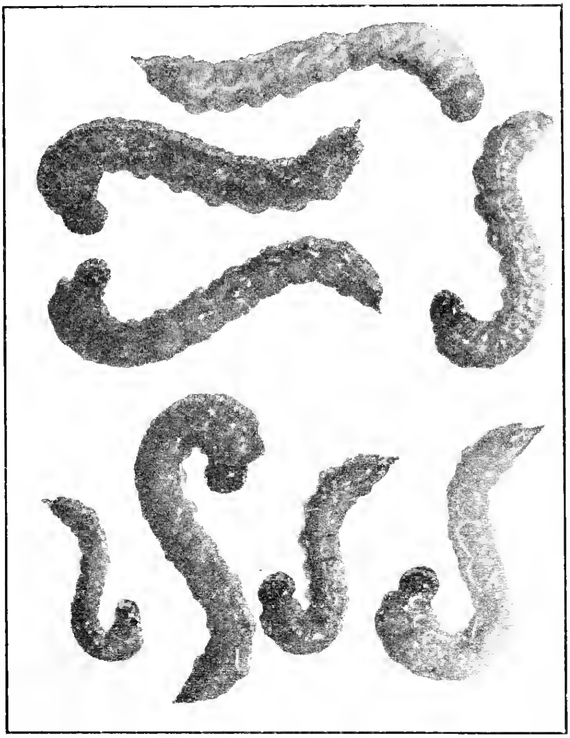

FIGURE 7.—Mature larvae of western grass-stem sawfly removed from their galleries. Enlarged 4 diameters

The full-grown larvae vary greatly in size, their growth being governed, as is usual in the case of such borers, by the quality and quantity of food consumed. Those living in wheat stems are much smaller as a rule than those found in rank-growing grasses such as Elymus. Measurements of a series of individuals give a range of from 8 to 14 millimeters in length and 1 to 2 millimeters in diameter.

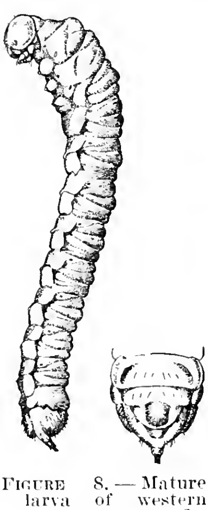

FIGURE 8.—Mature larva of western grass-stem sawfly. Enlarged 5 diameters

When mature the larva always seeks the extreme base of the stem, where it begins its preparations for hibernation. Its first move is to cut a neat V-shaped groove entirely around and inside the stem, usually at or a little above ground level. This groove never severs the stem completely, but so weakens it that the upper stalk, swayed by the wind, will break off completely when dry, leaving a stub that is very characteristic of the work of this insect. (Fig. 9.) In this simple manner the larva provides for the easy escape of the adult from the stub in the following summer. The length of the stub thus formed varies greatly. In *Elymus condensatus* it sometimes will project above the ground as much as 3 or 4 inches, while in other grasses, and especially in wheat, stubs can often be found less than an inch in total length.

Instances have been observed where two or more grooves had been cut inside the same stem, as if the larva had been uncertain as to the best place for severing the grass. After cutting its characteristic groove within the stem the larva forces a mass of the débris into the bore just below the groove and in this manner plugs the upper end of the stub that is to be left in the ground after the upper stalk has been broken away. (Figs. 9, 10, and 11.) This dry frass is packed firmly into its place, perhaps by means of pressure rather than by being cemented with a liquid furnished by the larva, since the plug is readily penetrated by moisture. This statement is somewhat remarkable in view of the fact that an undue quantity of moisture

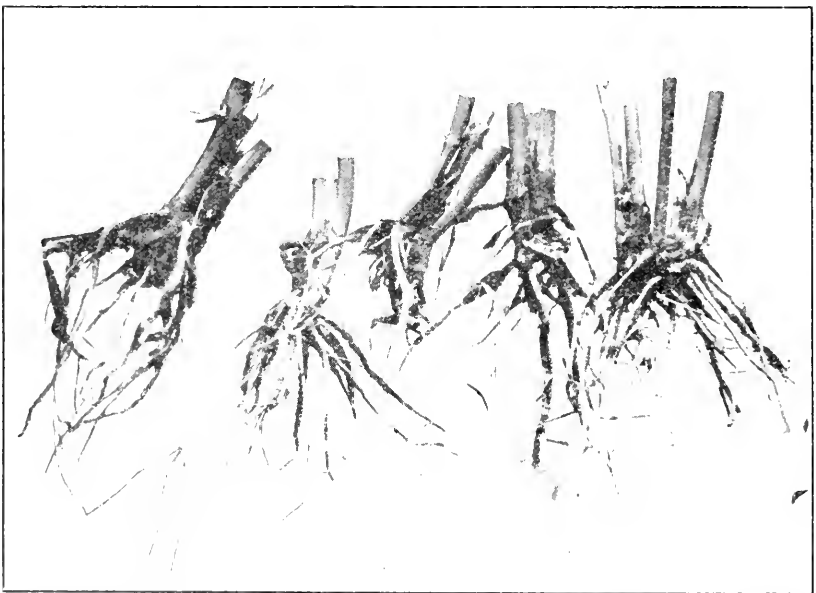

FIGURE 9.—Wheat stubs from Bottineau County, N. Dak., infested with the western grass stem sawfly

appears to have a disastrous effect upon the mature larva. One would suppose that these stubs, often wholly submerged in water-soaked earth for weeks at a time, would absorb, during the long period of hibernation, a fatal quantity of dampness from the rain or melting snow. There is more or less winter fatality and some of this may be due to moisture penetrating the stub.

On September 16, 1911, one of the larvae was removed from the hibernation chamber and placed in a small vial, still inclosed within the silken tube or cocoon, which was unbroken. For months this larva remained motionless except when the vial was exposed to bright sunshine, when because of the light or heat, or both, it would become active at once, and travel up and down within its cocoon in its efforts to escape. On January 20, 1912, to prevent the air in the vial from becoming too dry a small drop of water was introduced and the vial again corked tightly. An hour later it was noticed that the silk tube had collapsed and that the larva within was limp and apparently dying. The surplus moisture was removed quickly, whereupon the larva revived almost at once. If the same quantity of moisture had entered the stem where the larva was hibernating it probably would have caused its death. This experiment, taken in connection with others that were not so directly conclusive, seems to prove that the porous plug in the stub must in some way prevent the admission of an undue quantity of moisture into the chamber below, although water readily penetrates it.

The gallery below the plug is always entirely free from débris, forming a hibernation chamber and later a pupation cell. Within this chamber the larva lies with its head up and usually pressed against the barrier at the top, always on the alert to retreat downward at any sign of disturbance. It descends by alternately flexing and straightening the body, bracing itself first by the jaws, then by the caudal horn as it hitches its way down. In ascending, the caudal horn is thrust against the side of the gallery or the cocoon, the body is straightened, the jaws obtain a purchase to hold the distance gained, whereupon the body is again drawn up until the caudal horn is applied to the side wall for another push.

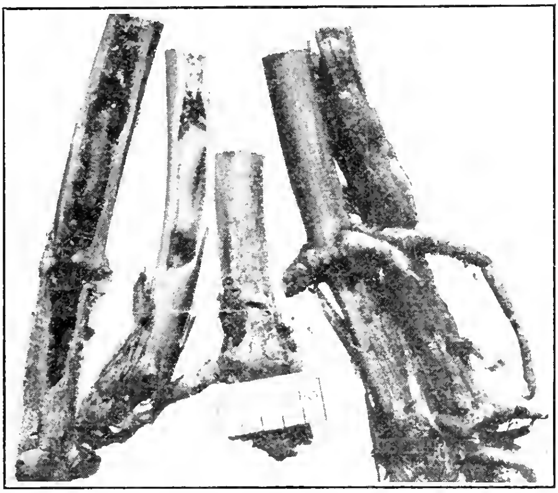

FIGURE 10.—Wheat stubs infested with western grass-stem sawfly, enlarged 3 diameters, the two left-hand ones opened to show hibernating larvae in situ

Late in the summer or in the fall the larva spins for itself within the hibernation chamber an almost transparent tube of filmy silken tissue. This silk tube is sometimes several times the length of the larva, is closed at both ends, and is free from the sides of the chamber, so it can often be readily withdrawn entire. When first constructed this fabric is comparatively strong and pliant but after some months it grows more brittle and is easily ruptured. As a rule it remains intact until the emergence of the adult. Even the presence of a half score of parasitic larvae often fails to wreck the delicate structure during the winter.

The longevity of the sawfly larvae is remarkable and is worthy of mention. On September 8, 1911, a number of stubs of *Elymus condensatus* containing Cephus larvae were gathered and set upright in sand within doors. From time to time this sand was moistened but finally was allowed to stand perfectly dry. During October, 1912, these stubs were examined and a number of the inclosed larvae were found to be still living, active, and unchanged. Four months later, 17 months from the time they were gathered, they were still alive and feebly active. Infested stubs of the same grass taken during September, 1912, and treated in the same manner contained at least one living larvae on February 23, 1916, three years and five months later. The others had nearly all died within about 30 months from the time they were gathered. It is possible that the lack of necessary moisture may account for the retardation of these captives. The same retardation of development, however, has been noted in the field. Inhabited stubs of the previous year's growth of grass and grain not infrequently have been found which contain larvae that were to all appearances entirely normal and active. It appears more than probable that in this manner the perpetuation of the species is assured in case of unfavorable seasons.

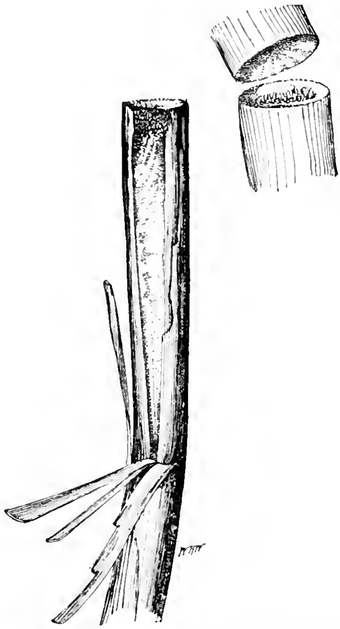

FIGURE 11.—Stems of wheat grooved internally by larvae of the western grass-stem sawfly

During the winter the larvae are, of course, frozen, or are chilled into immobility and show no signs of life when disturbed. As soon as the earth warms in the spring they again grow active and move freely up and down within the limits of the silk-lined hibernation chamber until the time of pupation arrives.

THE PUPA

The pupa when first formed is milk white, slender, and somewhat longer than the larva from which it was derived. Its average length is not far from 12 millimeters and its breadth is about 1.5 millimeters. The pupa (fig. 12) lies motionless within the silken pupation chamber or cocoon for probably a day or two, after which it again becomes active. When disturbed it will endeavor to escape the threatened danger by moving either up or down the tube, hitching itself along in much the same manner as the larva but going a lesser distance with each effort. Like the larva it is almost always found with its head pressed closely against the plug of frass at the upper end of the chamber. In a few cases pupae have been discovered heading downward in the stem. It is doubtful if these can reverse

FIGURE 12.—Pupa of western grass-stem sawfly. Enlarged to 3½ diameters

their position, but the adults which issue are probably agile enough to turn about and escape.

The duration of the pupal period is not known certainly, but is believed to be very brief, not more than a week at the most. After the first day the legs and body darken until they become a lustrous black within the transparent, almost invisible, filmy membrane in which they are inclosed. This membrane is often lacking and may occasionally be destroyed by the movements of the pupa within the chamber.

When fully mature the pupa changes within the cell to an active adult. This adult remains for a longer or shorter time in the cell before forcing its way upward through the plug or frass, placed at the upper end of the chamber by the larva nine months before, and emerging. The writer, by splitting stubs of grass or grain in June, has repeatedly liberated adults, which, when free, were able to take instantly to wing without any preliminary drying or other preparation.

A very few die within the cell, possibly because of lack of vitality needed to break through the stopper of frass above them. In cases where the girdling of the stem is inefficiently done, so that the grass stalk did not break off during the winter season, the adult dies as a matter of course, since these flies are not fitted with mandibles capable of biting through the woody stems of dry grass.

THE ADULT AND ITS HABITS

The adult *Cephus cinctus* is a beautiful insect with a polished black body marked by three prominent yellow bands across the abdomen. The legs are yellow and the wings smoke colored.

The description by S. A. Rohwer follows.

Length 7 to 12 mm. Head shining, polished; anterior margin of clypeus truncate with angles prominent and sometimes slightly denticulate; antennae usual for the genus; thorax shining but with setigerous punctures on scutum; sheath nearly parallel-sided but a little broader at base, apex truncate with corners rounded; hypopygidium rather narrowly subtruncate apically. Black marked with bright lemon yellow, amount and extent of yellow markings varying greatly; head of female usually black but more rarely with face entirely yellow or having yellow spots; head of male black but always with yellow on face; thorax black, the upper angle of mesepisternum, parapteron, and scutellum (usually) yellow; legs yellow with coxae, trochanters (occasionally both of these having yellow marks), bases of femora more or less, apices of tibiae and tarsi sometimes, black; hind tibiae and tarsi sometimes reddish yellow; abdomen black, spot or band on second tergite, band on third, fifth, sixth, and eighth tergites and lateral margins of tergites yellow, the size and extent of these markings varying and occasionally the fourth tergite having a yellow band; wings fuliginous, venation dark brown, costa and stigma yellow.

The female is noticeably larger than the male and is less active.

The characteristic attitude of the adults of either sex while at rest during the chill of the morning and after sundown is lying flat against the grass stem, head downward, the legs not spread but stretched in line with the body which is concealed behind the closely folded, smoke-colored wings. The ease with which such a strikingly colored fly, while in this position, can escape observation, is remarkable. The fly basks in the sun at midday, on the warm side of grass stems, with the wings partly spread and the legs outstretched. Like most Hymenoptera, this species is very partial to sunshine and rarely is seen abroad on a cloudy day. In fact, it is not then easy to find these flies at all, unless one is entirely familiar with their habits.

They are weak fliers and seldom travel to any great distance at one time. In Utah they commonly move about among the plants of bunch grass, making short flights from tuft to tuft. If the wind rises or the sun goes behind a cloud they promptly disappear until conditions again become satisfactory. The writer has never taken the adults at any great distance from their breeding places.

Their hovering flight is peculiar, the swaying motion of their bodies in the air reminding one of certain tipulid flies during their mating air dance. They often hover for a long time to the windward of a grass plant without alighting. The males are on the wing much more than the females. The adults are not at all timid and can often be readily taken from the grass stems with the fingers. When conditions are favorable the female is usually too intent on oviposition to be easily annoyed but if disturbed beyond endurance she quickly disappears, her dark color and slender body enabling her to vanish completely among the vegetation.

Copulation is very brief, usually lasting less than a minute.

The species is single brooded, the adults appearing during the spring and dying some time about midsummer.

The earliest individual met in Utah was taken in a net April 26, 1910, in an alfalfa field. Adults have been seen in the mountains late in July, and they probably linger longer than that, ovipositing in such green grass stems as they can find. Near Kimballs, in Utah, September 8, 1911, the writer took very young larvae from stems of *Elymus condensatus*, growing from plants that had been browsed by cattle and had thrown up fresh green stalks.

Norman Criddle states that in Canada the adults appear during the second week in June and may be met with until about July 10. Occasionally they may be found feeding on flowers. Fletcher took them in Canada on flowers of the tumbling mustard. The time of their appearance and the length of adult life are both largely governed by climatic influences and vary with the season.

When confined in emergence tubes or other limited places the males attack one another without mercy, using their jaws freely to snip off the antennae and, in some cases, the legs of their rivals. Singularly, very few of the females confined with them are thus mutilated.

OVIPOSITION

Weather conditions are always an important factor in controlling the oviposition of insects and they are of particular importance in the case of the Cephus. Only on bright, warm, still days are they to be found busy placing their eggs. In Utah, where the first studies of their habits were made, the mornings and evenings are chilly as a rule, hence the activity of these flies is confined to the hours near midday. They are usually the most active between the hours of 10 a. m. and 2 p. m.

The swaying of the grass and grain stems in the wind appears to be a hindrance to them in alighting and ovipositing, while a sudden mountain gust is apt to put an abrupt end to all efforts for the balance of the day. Sometimes on a still, sunny day they will spend much of the time quietly on the stems, while again, under apparently the same conditions, they are constantly in motion, flying and hovering a long time before alighting.

The female evidently selects the particular stem in which to oviposit, and once she has chosen and settled, she seldom changes to another stalk, although she may halt at several places on a single stem and attempt oviposition at each pause. Occasionally, after a hasty examination, she may again take to wing and make another choice. Repeated observations seem to have established the fact that one of the chief requisites of a proper stem is that it shall not yet have put forth a head. In all the instances where oviposition has been observed, the female has never been known to choose a stem with a head.

When she has made her selection of a suitable stem, the female usually alights about halfway up and runs briskly to the upper end, halting almost imperceptibly every few steps. The gait of an ascending fly is so characteristic that it determines with much certainty whether the individual is a female intent on oviposition.

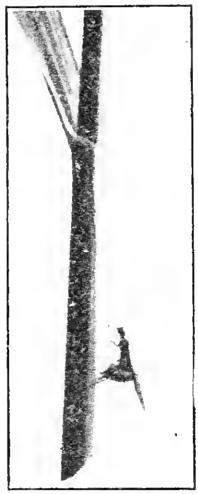

FIGURE 13.—Female of western grass-stem sawfly ovipositing. About life size

Arriving at the apex of the stem, after a careful survey of its condition, she frequently preens herself carefully. She then descends, exaggerating slightly the hesitating step by which she had ascended. The antennae are held in front of the head parallel with the stem as she moves, and she occasionally touches the surface of the stem with their tips. There is none of the rapid antennal vibration so common among the smaller chalcids and many other Hymenoptera. She gives no evidence of being in search of any particular point, but goes straight down the stem.

When satisfied with the location she halts abruptly, usually an inch or less above the second node from the top of the stem, slowly arches her abdomen and, clasping her hind pair of feet around the stem as far as they will reach, begins to drive the saws into the hard outer tissue. Figure 13 shows the attitude taken by females at this time, though they usually face downward. These saws are slightly curved, double, very thin, with serrated edges. (Fig. 14.) They are used to split the outer coating of the stem rather than to cut it, and they make an opening so small that it is almost impossible to find the scar after the wound has healed. These saws are gradually forced into the stem, the operation occupying a minute or more. In the field the female always heads downward during oviposition and the curve of the saw blades brings the tips, when fully inserted, in a line parallel with the axis of the stem. These are frequently partly withdrawn and their direction slightly changed. When the stem is in proper condition the saws are thrust in several times, as far as they will go, then withdrawn, the dorsal part of the pygidium being used as a fulcrum to extract them. They are inserted again, this time often with a twisting motion as if trying to enlarge the opening. They are finally forced in as far as possible, as is evidenced by the tenseness of the rear legs straining at the stem, and are held in this position for half a minute or more.

When busy with oviposition the sawflies seem oblivious to whatever is going on around them, and the writer has repeatedly watched, through a half-inch triplet, the female manipulating her saws. It is impossible to determine under the closest scrutiny just when the egg is passed into the stem. It is probably at the time when the female stands motionless after the saws have been driven in to their full length.

The function of these saws appears to be twofold. At Pinto, Utah, in June, 1912, the writer found that the eggs were invariably placed in a cell hollowed in the solid parenchyma of the stem of *Elymus condensatus*, this cell being a little larger than the egg. Besides piercing the stem, the saws are also of use in excavating this egg cell, in case such a cell is needed. At Kimballs near Salt Lake City, in

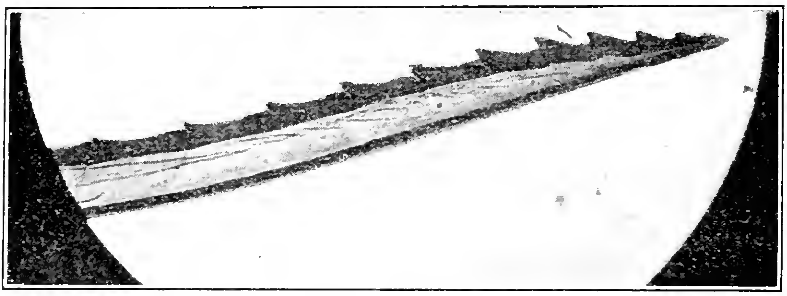

FIGURE 14. Saw of western grass-stem sawfly highly magnified

the same grass, the eggs were nearly always placed in the hollow part of the stem, lying free in the central cavity.

Normally but one egg is placed in each stem. However, no attention is paid to previous oviposition, and as many as five eggs have been taken from a single stem. As is stated elsewhere, only one of the larvae can possibly survive until fall.

The date of oviposition (fig. 15) varies with the latitude and the altitude. At Pinto, Utah, on the edge of the desert country and with a low altitude, newly hatched larvae were found June 14, 1912, while at Kimballs, 350 miles north of Pinto and with an altitude of 7,000 feet, oviposition was beginning during the first week of July in the same year.

Criddle states that in Canada most of the eggs are deposited in June. The date of oviposition in the Dakotas and in Minnesota is unknown.

KEY TO NORTH AMERICAN SPECIES OF CEPHUS

Through the courtesy of S. A. Rohwer, a key for the determination of the adults of known species of the genus Cephus occurring in North America is here presented.

Stigma and costa dark brown of a uniform color; mesepisternum black; femora black; apical tergite and venter black; face and scutellum black (face of male with yellow spots) ---------------------------- *pygmaeus* Linnaeus.[6]
Stigma in greater part and costa yellow; mesepisternum with the upper angle yellow; apical tergite and usually the venter in part yellow; femora usually mostly yellow; face and scutellum of female usually black but occasionally with yellow spots -- *cinctus* Norton

NATURAL CONTROL

Under normal conditions, when *Cephus cinctus* subsisted wholly on grass stems, its larvae were attacked by two or more species of parasites that destroyed numbers of them and kept them within reasonable bounds. Although the fly has begun to change its habits and to subsist to a certain extent on wheat and other small grains these parasites apparently are still confining their attacks largely to those larvae that they find in grass stems. The proportion of larvae parasitized in wheat stems, however, seems to be steadily increasing, and counts in 1927 showed 18 to 30 per cent of such larvae parasitized.

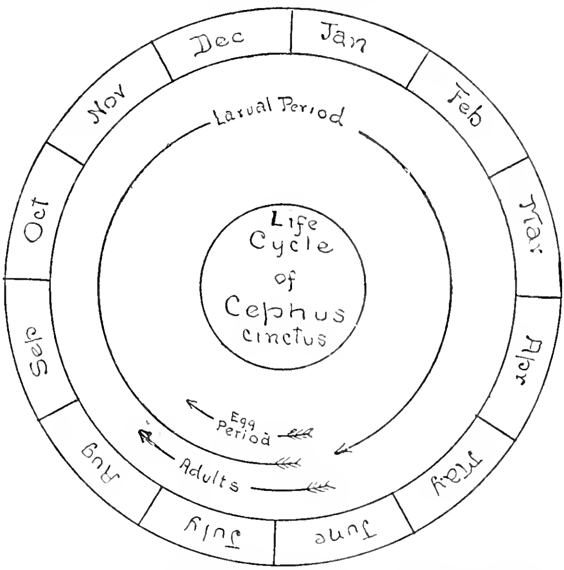

FIGURE 15.—Life-history diagram of the western grass-stem sawfly

The most common parasite found everywhere in the grasses is *Pleurotropis utahensis* Cwfd., a beautiful little bronze-green chalcid that was reared by the writer from numerous larvae taken near Salt Lake City, Utah, from hibernation cells of the sawfly. This species appears to kill the larva only after the latter has formed its hibernation cell. It is gregarious and seldom or never attacks its host singly. As many as 12 of its larvae have been taken from a single cell, but 5 or 6 is a more common number. These larvae are white and are from 2.5 to 3.5 millimeters in length. They are somewhat active and travel slowly about the cell when mature. They are often found crowded together in one end of the cell, but when disturbed will scatter about the chamber. (Fig. 16.)

Although this species is widely distributed and propagates in numbers it appears to destroy only a small percentage, possibly 10 per cent, of the Cephus larvae in the native grasses of Utah. In Bottineau County, N. Dak., it attacks the sawfly very freely in Bromus and timothy, and in some localities has killed more than 50 per cent

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[6] *Cephus pygmaeus* is not known to occur anywhere west of Pennsylvania but its habits are similar to those of *C. cinctus*.

of the Cephus larvae. Indeed, it and one other parasitic species are so numerous in these roadside grasses that it would seem poor policy to recommend the cutting of the grasses in midsummer as a measure of sawfly control.

A braconid, *Microbracon cephi*, described by A. B. Gahan [7] also attacks the larvae in grass stems, kills them before maturity, and spins a gray parchmentlike cocoon within the gallery, generally near its lower end. This cocoon is truncate at both ends, its disklike extremities completely filling the bore. The adult escapes by biting an opening through the stem in the vicinity of the cocoon.

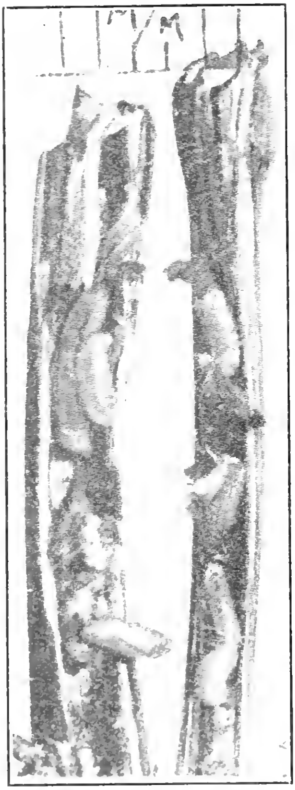

FIGURE 16. Larvae of *Pleurotropis utahensis*, a parasite of the western grass-stem sawfly, in situ

ARTIFICIAL CONTROL

From the foregoing sketch of the life history of the western grass-stem sawfly it seems obvious that this pest will have to be attacked while it is in the larval stage. The egg and adult stages are both brief and are clearly beyond the reach of control measures of any sort. For nearly 11 months the insect exists as a helpless larva, protected only by the grass or grain stem within which it lives. If this stem could be destroyed, the larva within would perish.

The first remedy that occurs to the farmer or the student of field conditions is the burning of the stubble in the fall or spring. It would seem a very simple matter to set fire to the stubble and destroy at least the majority of the sawfly larvae that are hibernating in it. But when one begins to examine the infested fields it is found that the insect has cut inhabited stems at the ground level or below, so it is often necessary to brush away the earth in order to find the stubs containing the larvae. So little heat is generated when stubble is burned that these subterranean stems could not possibly be harmed by the quick passage of the flames.

In 1907 Norman Criddle, in Manitoba, wishing to make a thorough test of this remedy, spread a layer of straw several inches deep over an infested spot in a wheatfield and set the straw on fire. More heat was produced than stubble alone could possibly make, the surface of the ground being too warm for the hand after the fire had died down. Even after this severe treatment it was found that, as far as could be learned by a minute search, not a single larva had suffered. They had simply retreated to the lower end of the hibernation cell and kept cool.

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[7] GAHAN, A. B. DESCRIPTION OF A NEW HYMENOPTEROUS PARASITE (BRACONIDAE). Ent. Soc. Wash. Proc. 20 (1): 18-19. 1918.

Another fact must be noted in this connection. When a field has been damaged seriously by the sawfly, the stubble remaining to feed a running fire is of necessity more scanty than in an uninjured field and consequently it would be exceedingly difficult to burn such a field under common conditions.

In Utah the bunch grass, *Elymus condensatus*, is much infested by this same fly and frequently is burned by fires that sweep the mountain sides. This Elymus forms dense sods, with stems often more than 3 feet in length, and the heat from its combustion is great. The writer has examined a large series of burned sods and has seldom discovered any injury to the larvae from the fire.

Some exceptions are to be noted. A few cases are on record where, because of favoring weather in the semiarid region, the wheat made an unusual growth of straw, and probably because of this rank growth the Cephus larvae cut the stems higher than usual, leaving stubs that projected an inch or two above soil level. To lessen the quantity of straw to be handled at threshing time it is the practice to raise the reaper cutter bar, leaving long stubble in the field. When such a field is burned over later the fire runs readily, and a large majority of the larvae are destroyed before they can retreat to the lower end of the hibernation cell. But such fortunate conditions seldom occur. As a rule, burning the stubble as a control measure is futile.

One method of control that has been highly recommended consists in plowing the infested stubble under in the fall or early spring before the flies have emerged. When properly done this method has been quite successful in preventing their emergence. But the manner of plowing is important. The furrow slice should be turned completely over in order that the top of the stubble shall come in contact with the firm bottom of the plow cut. Where this is done the flies are unable to make their way out of the stubs to reach the surface of the soil. The difficulty with this method lies in the fact that, unless great care is exercised, the furrow slice will not be wholly inverted and as a result the infested stubs will lie horizontally in the loose soil, thus allowing flies to emerge without much difficulty. There are almost always some cracks and openings in the furrow slice that permit easy egress. Because of these drawbacks less emphasis is now being placed on this method of control than formerly.

In the fall of 1916 the writer buried four lots of infested stubble in different depths of earth sifted and compacted by jarring. These were buried, one at 3 inches, one at 4, and two at 6 inches, in glass jars, 10 stubs in each of the first two, 20 in the other two. On August 6, 1917, these cages were examined, with results as follows:

Under 3 inches of earth all had emerged as adults.

Under 4 inches 1 larva had died, but all others had emerged as adults.

Under 6 inches 1 adult and 6 larvae had died in the cell; all others had emerged as adults, except 2 active living larvae which remained in the cell.

Under 6 inches 7 larvae had died in the cell; all others had emerged as adults.

Lumpy soil in the field might make it easier or harder for adults to emerge than fine soil in a jar, and this point is difficult to determine.

Cultural conditions in North Dakota are not favorable for burying the stubble by plowing. Spring wheat is followed in many cases by winter rye which is disked into the wheat stubble after harvest. This procedure leaves all the infested stems of wheat on the surface, and nothing could be more favorable for the escape of the adult flies in the following spring. The wheat stubble seems to be necessary in this region to hold the winter snow for the protection of the young rye, hence the farmers seldom or never plow the stubble under before sowing the rye.

Without any doubt grainfields in North Dakota and Canada are invaded regularly by sawflies that issue from grass growing along their borders. Although it might seem possible to decrease the numbers of the fly by mowing roadside and fence-row grasses in July, thus destroying the larvae always present in the stems of these grasses, careful study has proved that a large percentage of such larvae are parasitized, and therefore it would seem unwise to take steps that might diminish the number of parasites.

Previous to 1919 it had been stated with much confidence that durum wheat was nearly immune from the attacks of the sawfly. On the strength of these statements authorities were inclined to recommend the barring of Fife and Marquis and the softer-stemmed wheats from the areas of North Dakota and western Canada in the hope that by this means the work of the sawfly might be checked and a more certain harvest assured. It was readily seen that an immune wheat would solve the problem of the sawfly.

Observations made by the writer in August, 1919, and referred to on page 6, included in their scope an inquiry into the question as to the alleged immunity of durum wheat. Farm work was too far along at the date of this visit to permit of effective field work to settle the matter definitely, but several farmers informed the writer that durum had suffered severely that year, although not so much as either Fife or Marquis wheat, and the agreement on this point was general.

The apparent resistance of durum may vary from year to year and is possibly based on the relation of the date of the appearance of the adult Cephus to the rapidity of growth of the young grain. The stem of the durum wheat is more dense and unyielding than that of other varieties, and if a warm rainy spring should hasten its growth it might prevent the sawfly from placing many eggs. A number of unknown factors enter into this problem that hinder its complete solution at present.

Where practicable, rotation of crops is recommended, and especially the sowing of winter rye. This grain ripens early and therefore can be cut before the sawfly larva reaches the lower end of the stem. It joints early in the season and thus proves attractive for oviposition when the flies appear. In North Dakota rye is very hardy, and nearly a third of the rye crop of the United States has been grown in that State.

Farm practice that includes proper rotation, following small grain crops with some crop that does not serve as a host plant, should prove more or less effective in reducing the damage from the attacks of these flies. Oats and flax are entirely free from attack by Cephus.

SUMMARY

The western grass-stem sawfly (*Cephus cinctus* Norton) is a wasp-like insect that originally attacked no cultivated crop but inhabited the large-stemmed native grasses of the northern Great Plains. When such grasses began to be largely supplanted by wheat and other small grains, however, the insect attacked these and has gradually become a pest of considerable importance.

Although this species is found in most of the Western States from central Michigan and eastern Missouri westward to the Pacific it has thus far been injurious principally in the great spring-wheat districts of North Dakota, Montana, and the neighboring Provinces in Canada. Of the cultivated grains it prefers wheat but has been found feeding on rye, spelt, and barley to some extent.

The egg is laid within the stem of the host plant by means of a sawlike ovipositor with which the adult insect easily penetrates the tough outer wall of the stems. Hatching occurs in about one week, and by means of its powerful jaws the young larva feeds on the interior of the stem, moving up and down in its gallery until about the time the wheat begins to ripen. It then gnaws a groove on the inside of the straw completely around the circumference of it and at about the level of the soil surface. Afterwards, descending slightly lower in the underground stem, it fills the gallery above itself, and just below the groove, with a plug of frass, thus closing the upper end of the stub that is to be left in the ground after the upper stalk has been broken away. In this stub the larva spins a delicate silken tube and hibernates. Where more than one larva inhabits a stem the stronger insect devours the others, so only one individual remains at hibernating time. In the spring the larva again becomes active but finally changes to a pupa and this, a short time thereafter, changes to an adult sawfly, which presently forces its way out of the stub.

The principal injury occurs to the grain not so much from the quantity of food that the insect removes from the plant as from the breaking of the straw before or at harvest time as a result of the groove cut by the insect, which causes much of the grain to fall to the ground or lodge so that it can be harvested only with great difficulty.

When inhabiting the grasses this sawfly is largely controlled by its parasitic enemies, but in wheat and other small grains this beneficent agency soldem functions.

Several partially effective cultural methods have been tried in attempts to control the pest, and among those that show some promise of success is plowing the infested stubble under in such a manner that the entire slice is inverted, thus preventing the adults from emerging. A rotation from wheat to flax, oats, or other crops which are not affected by the sawfly has been found advantageous but no specific remedy for this insect is yet known. Under ordinary conditions the burning of the infested stubble in the fall or spring does not seem to heat the ground sufficiently to kill the larvae in the underground stems.

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November 14, 1929

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INVESTIGATIONS IN WEED CONTROL BY ZINC SULPHATE AND OTHER CHEMICALS AT THE SAVENAC FOREST NURSERY

BY

W. G. WAHLENBERG

Assistant Silviculturist, Northern Rocky Mountain Forest Experiment Station, Forest Service

UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D. C.

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INVESTIGATIONS IN WEED CONTROL BY ZINC SULPHATE AND OTHER CHEMICALS AT THE SAVENAC FOREST NURSERY[1]

By W. G. WAHLENBERG, *Assistant Silviculturist, Northern Rocky Mountain Forest Experiment Station, Forest Service*

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THE WEED PROBLEM AT SAVENAC NURSERY

Savenac nursery, located in western Montana, has a yearly output of about 3,000,000 coniferous tree seedlings and transplants. The annual cost of care during the first two years of seed beds that have not been treated chemically has been about $1.40 per bed of 48 square feet, and of this amount 56 cents, or 40 per cent, has been the cost of hand weeding.[2]

There seemed to be no hope of reducing this expense through the use of any type of cultivator or mechanical device for weeding because of the close stands in which trees are grown in the seed beds—often 100 individuals per square foot of surface. For like

[1] This publication is based upon 10 years of investigation begun in 1916 by P. C. Kitchin (*24*), who published a preliminary report in 1920. The experiments were continued by the author until the fall of 1925. The author wishes to express his thanks to those members of the Forest Service and others who have assisted in the preparation of this bulletin, with especial recognition of helpful suggestions from the Bureau of Chemistry and Soils, where soil tests were made, and from Carl Hartley, of the Bureau of Plant Industry.

[2] G. W. Jones, superintendent of Savenac nursery, furnished the cost data. The wage basis for all cost figures is $4 per day. Costs are expressed here on an area basis rather than on the basis of each thousand seedlings produced, because the number of weeds and the expense of removing them by any method varies more directly with areas than with density of the crop. No uniform costs per thousand tree seedlings can be given because the number of trees to a bed varies widely with the age class and the species grown.

NOTE.—Italic numbers in parentheses refer to "Literature cited," p. 33.

reasons no trial was made of the methods of preventing weed growth by laying down strips of heavy paper as in Hawaiian pineapple fields or of spreading paper by machine as in South African sugar-cane fields (*1*).

It is said that the sugar-cane sprouts successfully pierce the paper, but the tops of forest-tree seedlings could hardly be expected to do this. Roots from seeds germinated on top of paper might be able to penetrate, but this was not tried. The Norwegian method of controlling weeds in forest nurseries by laying boards between trees in transplant rows did not seem practicable for a large nursery in a country where labor costs are high. Because physical methods held forth so little promise, the investigations were centered on chemical means of control, keeping in mind the possible injury to tree crops and the soil.

Although what appears to be quite a satisfactory chemical method has been developed at the Savenac nursery, it is to be expected that the reaction of any chemical substance will vary with different soils, weeds, and crops, and that in other places the Savenac weed treatment may possibly require considerable modification before it can yield the best results.

Analysis of the Savenac nursery soil in 1913 by the Bureau of Soils showed that it contained 0.41 part of lime, 0.24 part phosphoric acid, 0.37 part potash, and 0.11 part of nitrogen. In 1921 a qualitative microscopic examination indicated very good physical properties in the soil, a high percentage of granular or " crumb " structure, and highly oxidized soil minerals. There was a very fair amount of organic matter but a large part of it was not well decomposed. The soil contained no lime in the form of carbonate or phosphate and had an acid reaction, attributable to the use of slightly acid irrigation water and to lack of rapid percolation through the subsoil. Potash feldspar (orthoclase and microcline) and potash mica (muscovite and biotite) were fairly plentiful, especially the feldspar. These minerals should slowly yield their potash under the process of weathering. Lime-soda feldspar (plagioclases) were present. These will probably weather and decompose more rapidly than will the potash feldspars.

Of the annual output of 3,000,000 trees 85 per cent are western white pine (*Pinus monticola*), and western yellow pine (*P. ponderosa*). The remainder consists of Engelmann spruce (*Picea engelmannii*), Douglas fir (*Pseudotsuga taxifolia*), western larch (*Larix occidentalis*), and western red cedar (*Thuja plicata*). The experiments detailed here dealt principally with the two pines and the spruce. The trees remain in the nursery from two to five years, but the majority are 3 years old when planted on the denuded mountain slopes. Field peas are used as a green fertilizer crop.

The three most troublesome weeds[3] at the nursery are field or sheep sorrel (*Rumex acetosella*), common timothy (*Phleum pra-*

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[3] According to Cox (8) a weed has been defined as a plant out of place or a plant which has not yet found its proper use, but in the minds of most people a weed is simply a wild plant that has the habit of intruding where not wanted. Both are right. Generally weeds are worse than useless when they occur on cultivated soil, but it is only fair to mention certain values which have been recognized as belonging to this class of agricultural pests. Just as a sawmill company would do well to investigate the possible commercial value of its waste material before investing in expensive equipment for its disposal, a forester should consider the possible value of weeds before expending much

tense), and white clover (*Trifolium repens*). These are all very prolific. It is impossible to remove the sorrel by hand and get all of the root system except when the seedlings are very young. The roots send runners far and wide. When roots 2 or 3 feet long are extracted they often do considerable damage by uprooting tree seedlings or disturbing the roots of many trees. The broken sorrel roots remain in the ground to sprout new plants. Clover and timothy are important because of their abundance and their bushy root systems. Although these three weeds deserve especial attention there are many others which in the aggregate give as much trouble.[4]

The source of weed seeds is a point to be considered since it is natural to think that chemical methods might not be necessary or that hand weeding might be made much less of a problem if access of many seeds to the nursery soil was prevented. The principal means by which seeds are introduced are water, manure, mulch, and wind. The water supply for irrigation and sprinkling is obtained from open ditches which carry many weed seeds produced along their borders or in mountain meadow land along the creeks from which the water comes. This is a common source of weed seed in many localities (*12*). Various methods of filtering out this seed have been tried, but so far none has been succeessful. Filters cause much trouble by clogging up with vegetal matter and decreasing the water pressure in the sprinkling system. Manure used as fertilizer contains numerous weed seeds that may not be killed by heat and steam treatments, although a period of one year is generally sufficient to kill weed seeds in compost containing manure. Straw used as mulch usually carries seeds. Sand used as covering for tree seeds after sowing is a river-washed product and should be fairly free from seeds, but probably contains a few. Wind, like water, is a rather constant means of weed-seed distribution. It is improbable, therefore, that weed growth at the nursery will ever be controlled by preventing the access of seeds.

Seeds already in the soil are the next consideration. The operations of plowing and cultivating must bury a great many seeds and unearth others, some of which probably retain their vitality for several years. An experiment started in Virginia by Duvel and reported by Goss (*16*) showed that seeds of most weeds, if ripe when plowed under, will not perish in the soil during the period of any normal crop rotation. Among the many weeds studied were the same species of clover and timothy that are troublesome at Savenac nursery. Of 200 white clover seeds 3 per cent, and of 200 timothy seeds 22 per cent, grew after having been buried 8 inches deep for 10 years. Bit-

money in eradication or in studies of methods of control. Campbell (6) points out the possibility that deeply leached nitrates can, in part, be returned to the upper surface layers of soil by the growth and decay of certain species of weeds. Early, late, and winter annuals appear to conserve nitrogen at times when no cultivated plants are present on the land. In places, weeds may prevent or retard soil erosion. They may sometimes be utilized in compost or as silage, or serve some other purpose in a minor way as a by-product from cultivated land, but their value seems to be limited to purposes which can be more efficiently served by the use of soiling crops.

[4] Miscellaneous weeds, as follows, have been identified: Woolly yarrow (*Achillea lanulosa* Nutt.); rutabaga (*Brassica campestris* L.); blooming sally (*Chamaenerion angustifolium* (L.) Scop.), commonly known in the western mountains as "fireweed," but not the same as *Erechtites hieracifolia*, fireweed); lambs-quarters (*Chenopodium album* L.); cotton cudweed (*Gnaphalium palustre* Nutt.); Purslane speedwell (*Veronica peregrina* L.); western stickseed (*Lappula occidentalis* (S. Wats.) Greene.); groundsmoke (*Gayophytum ramosissimum* Torr. and Gray); red sandspurry (*Tissa rubra* (L.), Britton); phacelia (*Phacelia heterophylla* Pursh.); Arctic pearlwort (*Sagina saginoides* (L.) Britton); houndstongue hawkweed (*Hieracium cynoglossoides* Arv.-Touv.).

ter dock (*Rumex obtusifolius*), a broad-leaved species belonging to the same genus as the troublesome sheep sorrel, germinated 82 per cent of its seeds under the same conditions. More extreme cases of longevity of seeds in the soil are occasionally recorded. Brenchley (*5*) in reporting experiments carried out at Rothamsted claims a survival of 60 years for the seeds of certain weeds common on cultivated soil. Enough has been done to indicate clearly that buried seeds should not be ignored as a source of weeds.

Weeds are a problem in many forest nurseries. There is very little hope that the harm done by weeds in competition with tree crops can be offset by any use of weed growth as a by-product of the land. Nor is there much hope of preventing the access of weed seeds from their varied sources. Once in the soil the vitality of some seeds may be retained for long periods. The growth of weeds is natural and seems almost inevitable. Removal of weeds by mechanical means is not only very expensive but also is often injurious to the tree seedlings. Removal by chemical methods, if effective, meets these difficulties very satisfactorily.

PREVIOUS AND FUNDAMENTAL INVESTIGATIONS OF TOXIC SENSITIVENESS IN PLANTS

Much of the work already done on chemical methods of eradicating weeds has been confined to poisoning the tops of weeds already established. For this heavy doses of poison are necessary. Also, the poison is not applied until after considerable damage may have been done by the weeds. The advantage of any practical methods of using smaller quantities of poison in the soil is obvious. By such methods weed seeds would be kept from sprouting or at least the seedlings would be prevented from appearing above the surface of the soil. The consideration of a practical means to this end involves a study of the relation of plant life to toxic materials, such as zinc and copper salts, the materials used in the work reported in this bulletin. Fortunately there is already some literature available on this subject.

Baumann (*3*) experimented with nutrient solutions with the object of determining the safe and the fatal limits in quantity of soluble zinc salts for different plants. He tested the effects of zinc sulphate at the rate of 44 milligrams per liter on plants of 13 species belonging to seven families and found that all except the conifers were killed. *Pinus sylvestris* and *Picea excelsa* stood out above all others as the only plants that grew well in a solution containing 10 milligrams of zinc per liter of water.

Work with soil cultures showed that not only does the sensitiveness of different species vary greatly, but concentrations which stimulate a plant in soil may be toxic in sand. Humus was the most absorbent soil for zinc salts. The absorptive power decreased as the soil grew poorer and apparently was weakest in sand. The presence of carbonic acid appeared to increase susceptibility to injury from certain zinc salts. The avenue of injury seemed to be an effect of zinc on chlorophyll and photosynthesis. If so, a comparison of the dry weights of plants produced with and without zinc should indicate the extent of injury, because the bulk of plant material is a product of photosynthesis. As indicated by the experiments of Storp in 1883 (*39*), the formation and function of chlorophyll appeared to be reduced by zinc compounds. Brenchley (*4*) pointed out that such a hypothesis is supported by the fact that in many fungi and higher plants without chlorophyll the toxic action of zinc is not evident. Javillier (*21*, *22*, *23*) found that zinc was contained in many parts of a large number of plants and that it was particularly abundant in conifers. He concluded that plants which contain chlorophyll are benefited by the action of small amounts of zinc, which act perhaps as a catalytic agent in the metabolic process.

This conclusion does not necessarily conflict with that of Storp, if it be accepted that very small amounts of poison often act as stimulants to plant cells. Evidence in favor of such a view is offered by Rusk (*35*) who, working with leaf cells of *Elodea canadensis*, reports the effect of zinc sulphate on protoplasmic streaming. Brenchley (*4*) reviewed the work of several investigators and concluded that although it was still uncertain whether or not higher plants grown in water cultures are susceptible to stimulation by zinc salts except at exceedingly great dilutions, in soils cultures containing zinc the fact of increased growth seemed to be more firmly established.

One compound of zinc was included among the many substances tested as soil disinfectants by Hartley (*18*). At Halsey, Nebr., he applied a water solution of 0.281 ounce (nearly 8 grams) of zinc chloride per square foot. The plot was sown with *Pinus resinosa* 17 days after treatment and 28 days later 5 weeds were counted, 4 of grass, and 1 of Mollugo. In the untreated check-plots grass was abundant and Mollugo predominant among other weeds.

The possible beneficial action of zinc on plants does not seem to have been demonstrated very clearly by the early workers, although Mazé (*27*) furnished some evidence of the indispensable nature of zinc for maize, and more recently McHargue (*26*) spoke of the widespread occurrence of small quantities of zinc in soils, plants, and animals and inferred that it performs important functions in metabolism. The failure of earlier experiments to show definitely that zinc is essential to plants is attributed by Sommer and Lipman (*37*) to imperfections of technic, such as the use of ordinary glass containers from which the culture solutions dissolved out appreciable amounts of zinc. They used boro-silicate (or Pyrex) glass containers in their tests with zinc and employed special precautions to exclude dust and other impurities. Wherever possible the seeds were cut off from the seedlings within a few days after germination so as to deprive the seedling of as much as possible of the stored food material in the seed. By these methods Sommer and Lipman confirmed the results of Mazé and presented striking evidence of the indispensable nature of zinc for dwarf sunflowers and barley. They concluded that zinc, like boron, is absolutely essential to the life and growth of certain higher green plants and probably for all of them. Sommer (*36*) later reported that even where the early development of kidney and broad beans appeared normal on plants lacking zinc the leaves began to fall, few blossoms were produced, and the plants declined rapidly in the flowering stage, producing no seed. Reproduction as well as development was normal in plants provided with zinc.

Soluble copper salts have, on the other hand, been found to be universally detrimental to plants. Haselhoff (*20*) found that these salts injure the soil in two ways. (1) Nutrient salts in the soil, especially those of calcium and potassium, enter into chemical combination with the copper salts, are rendered more soluble, and readily leach away. (2) This double decomposition produces copper oxide which remains as an injurious ingredient.

Chemical weeding of coniferous seedlings in nursery beds had its inception in experiments conducted for another purpose. When sulphuric acid was applied to soil as a disinfectant to control damping-off fungi, marked reduction in weeds was noticed at a number of nurseries, according to Hartley and Pierce (*19*).[5]

Early work in applying chemicals to the soil at Savenac nursery has been reported by Kitchin (*24*) and requires only brief mention here. In the spring of 1916 copper sulphate and zinc chloride were compared with sulphuric acid in various quantities as to effectiveness in weed control. One-half ounce (about 14 grams) of zinc chloride and one-quarter ounce (about 7 grams) of copper sulphate per square foot were found to be much more deadly to weed seed than the acid in any strength tested. These results led directly to more intensive experiments.

THE FIRST TESTS OF GERMINATION OF WEED SEEDS AND WESTERN WHITE PINE UNDER CHEMICAL TREATMENT

METHODS AND PROCEDURE

The first intensive tests of chemical treatment at Savenac were made in the fall of 1918. During the first half of September, the usual period for sowing western white pine, 84 small plots were installed to test the effect of zinc sulphate ($ZnSO_4.7H_2O$ white vitriol), zinc chloride ($ZnCl_2$), and copper sulphate ($CuSO_4.5H_2O$ blue vitriol) in quantities varying from 4 to 12 grams per square foot. A block of 28 plots was devoted to each of the three chemicals. In each block were four units of seven plots each. Two of these units were used for germination counts and root examinations, the seedlings being pulled out, examined, counted, and recorded at approximately 10-day intervals during the season. The other two units in each block were allowed to grow unmolested for observation of thrift and survival. In each unit the plot tests were designated A, B, C, D, E, F, and G. The upper 2 inches of soil in all plots except G was sterilized, in part at least, by heating, and was sown with western white pine, clover, sorrel, and timothy—200 seeds of each species in each plot. All except F and G were then treated chemically.

Bottomless wooden containers, 1 by 2 feet, and 10 inches deep, were sunk in the soil as frames for the plots (pl. 1, A) in order to promote uniform growing conditions in the absence of an "isolation strip" or border of similarly treated seed bed. They served to prevent the loss of soil solutions by capillary transfer in a hori-

[5] The acid treatment was found successful in many places with a variety of soils. An exception occurred near Garden City, Kans., where the acid produced effervescence and did not affect the fungus. This has been attributed to a high carbonate content and consequent alkalinity. The experience indicates that a chemical treatment found successful on one soil may not serve the purpose on a different soil. At this nursery copper sulphate and zinc chloride were then tried and proved to be successful disinfectants for damping-off fungi.

zontal direction and to prevent the border plants from benefiting by an extension of their roots into the surrounding unoccupied soil space. As a further precaution to avoid the passage of soil solutions from one plot to another, and to allow working space, the frames were separated from one another by at least a foot.

In the process of sterilization the upper 2 inches of soil in each frame was removed, soaked in order to swell any weed seeds it contained, exposed to steam heat for an hour to kill these seeds, and then replaced in the frames.

Pine seed was sown at the depth of one-quarter of an inch and weeds at a depth of one-eighth of an inch. Care was exercised to make these depths uniform by the use of specially constructed sliding eveners.

The chemical applications followed immediately after the sowing. One liter of solution of various strengths was applied to each square foot of soil surface. (Pl. 1, B and C.) Accidental sowing of weed seeds was prevented by filtering the water used. Plots were tightly covered with half-inch mesh wire netting to exclude rodents and birds, and with cheese cloth fine enough to exclude the entrance of further weed seed. The cloth cover was kept throughout the season of 1919 on the series used for germination counts, but was removed from the survival series when germination appeared to be complete.

RESULTS

Seeds of the same species that were not sown but were already buried in the soil of the experimental plots do not seem to have produced sufficient seedlings to interfere with the experiment. This is indicated by a comparison of Plots F and G in Table 1. Of the other native species of weeds the sterilization killed only about half, but the remainder were effectively killed by the chemicals as is indicated by the figures for "other weeds" in Table 3.

TABLE 1.—*Ineffectiveness of unsown seed in experimental plots as shown by weed germination, 1919* [1]

Plots	Treatment	Clover	Sorrel	Timothy
		Number	*Number*	*Number*
F	Sterilized soil; 200 seeds of each species sown	93	45	193
G	No sterilization; no sowing	4	0	1

[1] Each figure is an average of six plots.

As the object of this study was to find a chemical treatment that did not injure pine stock in any way, the degree of injury to root tips of pine seedlings should be reviewed first, in order that the results from seed germination in those plots where pine was injured may receive only the secondary consideration they merit. The system of pulling out newly germinated seedlings at intervals of about 10 days gave an excellent opportunity to observe the roots of a large number of plants. Table 2 and Figure 1 indicate the percentage of pine seedlings with injured root tips. The injurious effect of copper sulphate was most severe. Death of plants resulted from failure of the roots to establish themselves in this soil. What few root tips had penetrated the soil were dark brown, curled, and warty in appearance. The zinc salts did not cause the pine seedlings to produce the dark brown, warty root tips, but the injured growing points were fatally curled and crumpled.

TABLE 2.—*Extent of chemical injury to western white pine seedlings from various chemical soil treatments*[1]

Plot	Salt per square foot	Proportion of germinated seedlings with root tips injured by different treatments			Plot	Salt per square foot	Proportion of germinated seedlings with root tips injured by different treatments		
		$ZnSO_4$	$ZnCl_2$	$CuSO_4$			$ZnSO_4$	$ZnCl_2$	$CuSO_4$
	Grams	*Per cent*	*Per cent*	*Per cent*		*Grams*	*Per cent*	*Per cent*	*Per cent*
A	4	0	0	18.9	D	10	7.1	25.8	86.3
B	6	0	0	53.5	E	12	9.8	35.2	95.0
C	8	0	29.0	67.1	F	0	0	0	0

[1] Each figure based on 1 plot of 200 seeds.

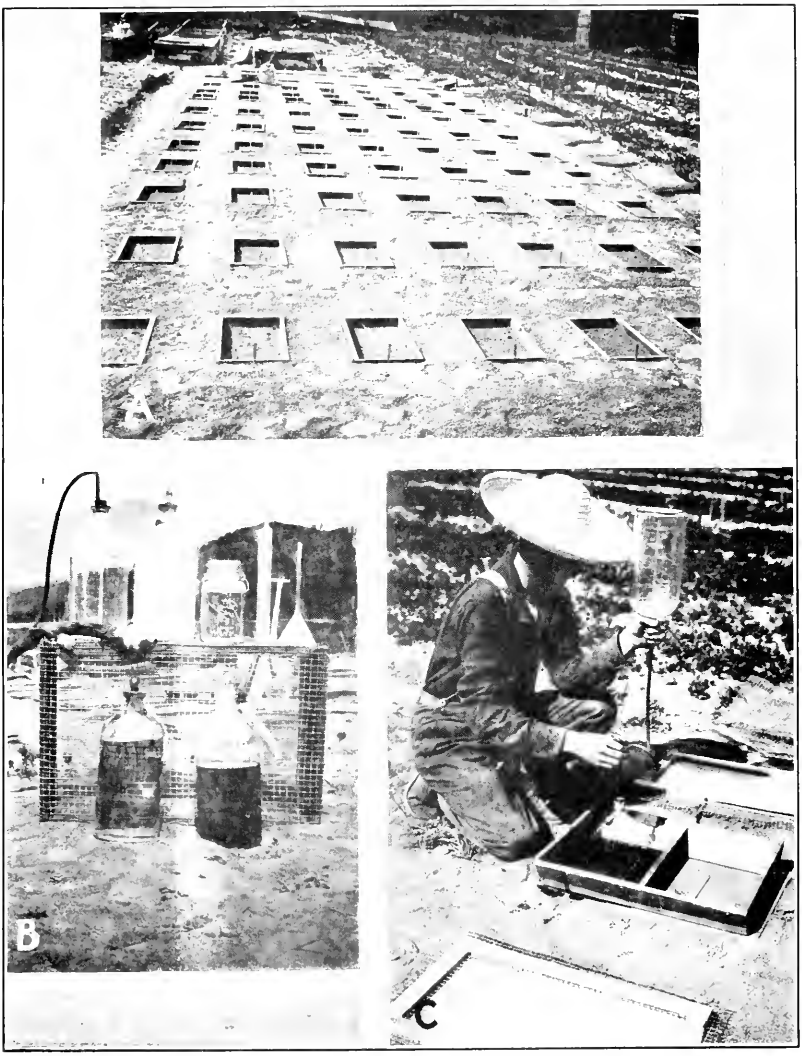
The effect of different soil treatments on the total number of germinations of pine and weeds in 1919 and 1920 is shown in Table 3.

TABLE 3.—*Influence of various chemical treatments on pine and weed seed, as shown by number of seeds germinating in 1919 and 1920*[1]

Plot	Salt per square foot used for soil treatment	Western white pine			White clover			Sheep sorrel			Common timothy			Other weeds			All weeds		
		1919	1920	Total	1919	1920	Total	1919	1920	Total	1919	1920	Total	1919	1920	Total	1919	1920	Total
	Zinc sulphate:																		
F[2]	Control	136	1	137	94	23	117	44	0	44	211	1	212	38	143	181	387	167	554
A	4 grams	139	1	140	66	18	84	26	3	29	169	0	169	0	14	14	261	35	296
B	6 grams	144	5	149	30	15	45	12	7	19	111	1	112	0	11	11	153	34	187
C	8 grams	151	4	155	49	9	58	16	3	19	116	0	116	0	5	5	181	17	198
D	10 grams	148	5	153	14	10	24	6	4	10	79	0	79	0	1	1	99	15	114
E	12 grams	162	3	165	23	15	38	9	8	17	60	0	60	0	0	0	92	23	115
	Zinc chloride:																		
F	Control	115	1	116	97	17	114	31	3	34	191	1	192	26	127	153	345	148	493
A	4 grams	137	4	141	45	25	70	21	8	29	133	1	134	0	15	15	199	49	248
B	6 grams	137	7	144	18	17	35	6	2	8	62	0	62	0	2	2	86	21	107
C	8 grams	137	7	144	4	4	8	6	1	7	72	0	72	0	0	0	82	5	87
D	10 grams	138	8	146	11	3	14	1	7	8	73	0	73	0	0	0	85	10	95
E	12 grams	142	10	152	9	1	10	8	1	9	49	1	50	0	0	0	66	3	69
	Copper sulphate:																		
F	Control	138	1	139	87	21	108	59	2	61	178	0	178	39	251	290	363	274	637
A	4 grams	158	1	159	81	20	101	7	1	8	2	0	2	0	61	61	90	82	172
B	6 grams	141	2	146	34	12	46	4	6	10	0	0	0	0	6	6	38	24	62
C	8 grams	134	3	137	21	7	28	6	2	8	0	0	0	0	1	1	27	10	37
D	10 grams	137	5	112	9	4	13	3	2	5	0	0	0	0	0	0	12	6	18
E	12 grams	124	1	125	1	3	4	1	2	3	0	0	0	0	0	0	2	5	7

[1] Figures are the average germination from two plots each sown with 200 seeds of each species in the fal of 1918.
[2] The presence of more than 200 timothy seedlings in 1 of the F plots and numerous other weeds indicates the germination of native seeds that were in the soil before sowings were made.

The action of zinc sulphate raised the germinative capacity of western white pine in every test. It greatly reduced the germination of clover, sorrel, and timothy seed, although not in direct proportion to the amount applied. In 1919 the sprouting of miscellaneous volunteer weeds was eliminated on all plots, and in 1920 the number of volunteer weeds was less than 10 per cent of the number in control plots.



INSTALLATION AND TREATMENT OF PLOTS

A.—Plots with 10 by 12 by 24 inch bottomless frames installed.
B.—Sprinkling apparatus, with other bottles containing stock solutions of zinc sulphate, zinc chloride, and copper sulphate; also hose with filter nozzle to catch seeds in the water supply.
C.—Method of chemical treatment, with a wooden "funnel" dividing the plot into two equal areas of 1 square foot each and preventing the loss of the solution from the plot. Treated plots at each side are covered with a cheesecloth and wire screen to keep out weed seeds as well as birds and rodents.

The action of zinc chloride was similar, with more pronounced and fairly regular elimination of the weeds, both sown and volunteer.

Copper sulphate stimulated pine considerably in the 4-gram test, and somewhat less in the 6, but heavier applications slightly reduced the number of germinations. Clover germinations were greatly reduced by applications of more than 4 grams. Sorrel and timothy were hit hard by all applications, especially timothy. Most of the miscellaneous weeds were as much reduced by light applications of this salt as they were by the other salts, and were eliminated by the heavier applications.

The pine seeds which come up during the season following sowing are the ones which must be depended upon for the crop, for the others, a year younger, do not ordinarly have time to develop sufficiently to be suitable for field planting. It may be seen from the

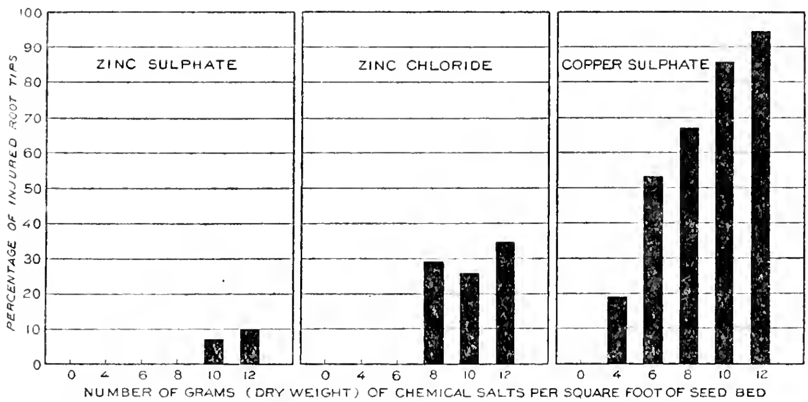


FIGURE 1.—Extent of chemical injury to root tips of western white pine

figures in Table 3 that all of the salts used, and especially the zinc chloride, slightly increased the number of pine seeds which did not sprout until the season of 1920.

It is essential not only that as many as possible of the pine seeds come up during the first season, but that the germination of these seeds should not linger. Prompt and complete sprouting of seeds in the spring months results in regular and satisfactory stands of seedlings. Stragglers are often too weak and tender to withstand the hot summer sun or the fall frosts. The application of shade, which is expensive, may not save these weaklings, and even if it does they are quite likely to be rejected along with those of the following season when field-planting time comes. Therefore this study would not be complete without a consideration of the effect of the chemicals on germination energy or seasonal promptness, as shown in Table 4.

TABLE 4.—*Effect of various chemical treatments of the soil on promptness of germination of western white pine seed* [1]

Salt per square foot used for treatment	Percentage of total germination at successive observations						
	May 7	May 15	May 26	June 6	June 18	June 30	July 14
Zinc sulphate:	*Per cent*	*Per cent*	*Per cent*	*Percent*	*Per cent*	*Per cent*	*Per cent*
Control	0	18.5	93.3	98.5	100		
4 grams	0	27.5	97.1	99.3	100		
6 grams	.7	16.9	95.8	99.3	100		
8 grams	1.3	44.4	98	100			
10 grams	1.4	29.3	98	100			
12 grams	3.7	40.3	97.5	100			
Zinc cloride:							
Control	.9	11.5	94.7	100			
4 grams	0	11.8	87.5	96.3	100		
6 grams	.7	13.2	90.4	97.8	100		
8 grams	1.5	22.2	96.3	100			
10 grams	0	34.3	96.4	100			
12 grams	1.4	28.6	93.6	99.3	100		
Copper sulphate:							
Control	0	13.8	96.4	100			
4 grams	.6	18.6	93.6	94.4	100		
6 grams	0	8.4	93	100			
8 grams	0	9.0	84.9	99.2	100		
10 grams	.7	9.5	83	98.4	99.2	100	
12 grams	0	2.5	79.1	96	97.6	99.2	100

[1] Figures are based on the average results from two plots each sown with 200 seeds and treated chemically in the fall of 1918.

The copper sulphate in all strengths definitely retarded germination, the apparent stimulation produced by the 4-gram application proving but temporary. On the other hand, both of the zinc salts and especially the zinc sulphate seemed to stimulate germinative energy. In Figure 2 a comparison is made of promptness of seed sprouting under the treatments that did not result in root injury to the pine seedlings. (Table 2.) The criterion of promptness or retardation of germination illustrated in Figure 2 lies in the relative position of the curves above or below the solid-line curve representing the behavior of seeds in the untreated soil. This solid-line curve indicates that without treatment 18 per cent of the germination had occurred by May 15 as compared with 13 per cent under the 6-gram zinc chloride treatment and 44 per cent under the 8-gram zinc sulphate treatment.[6] The apparent superiority of zinc sulphate over zinc chloride stood out in these tests, the seeds from the 8-gram zinc sulphate treatment maintaining their lead as indicated by the uppermost curve of Figure 3.

An interesting point observed in the plots kept covered with cheesecloth during 1919 was the action of zinc and copper salts on the growth of bryophytes. There was as much or even more such growth on the plot treated with 4 grams of zinc sulphate per square foot as on the untreated control, but the growth diminished rapidly through the 6, 8, and 10 gram plots and was practically nil in the 12-gram plot. With the other two chemicals there was some growth in the 4-gram plots, but not as much as in the control plots, and in the plots receiving heavier applications there was no sign of bryophyte growth. Again in the spring of 1920 it was noted that

[6] The evidence that this rather striking increase in germination with the 8-gram zinc sulphate treatment was due to any inherent superiority of zinc sulphate over zinc chloride is weakened by the inconsistent position of the 4-gram zinc sulphate curve between the curves for the 6 gram and 8 gram doses of this salt, and also by the small basis in a single test in which only 400 seeds were sown. If zinc ions are the only active agents, zinc chloride should be found as good in every way as zinc sulphate.

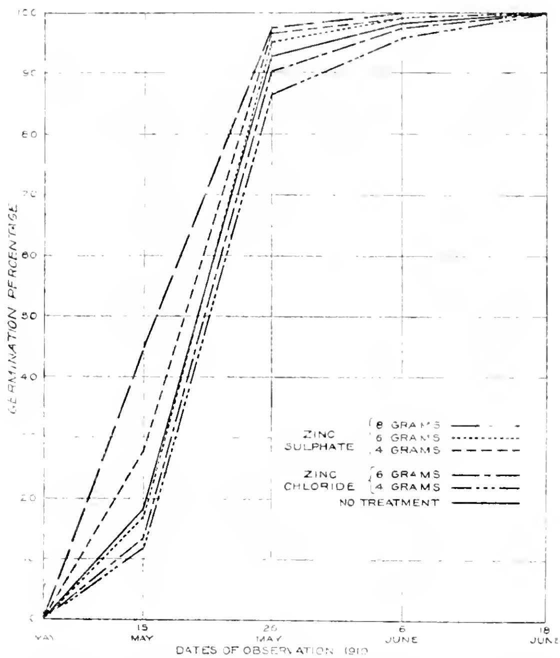


Figure 2.—Germinative energy of western white pine seed as influenced by treatment with zinc salts at different rates per square foot of seed-bed surface

zinc chloride, copper sulphate, and zinc sulphate had a restraining effect on bryophyte growth in the order named, and the inhibitory effect appeared to vary directly with the quantity of salt applied.

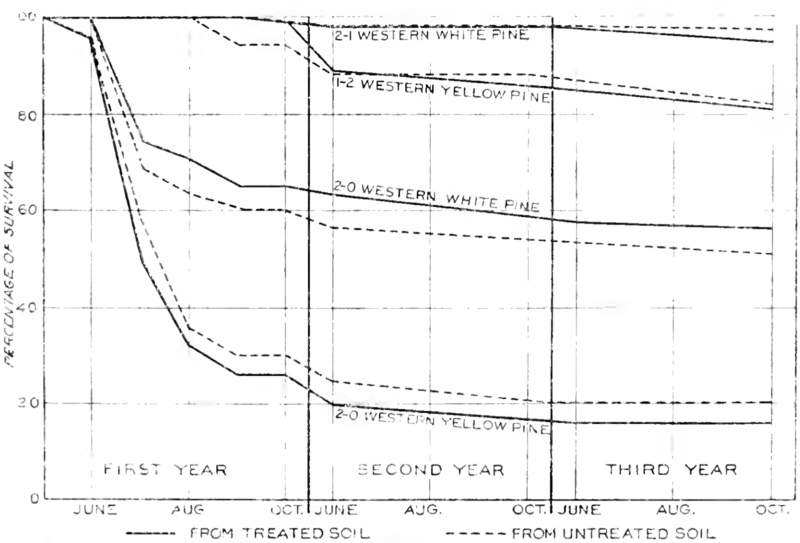


Figure 3.—Similarity of survival of planted trees grown on treated (zinc sulphate) and untreated nursery soil

As all the chemical treatments were efficient in reducing the germination of weed seeds, the selection of the most practical treatment depends upon relative effects on the pine seeds and seedlings. Within the range of the doses tested, the effect on the trees may be briefly restated as follows: In increasing the total number of seeds that came up the copper sulphate was least active, the zinc chloride next, and the zinc sulphate most active. Copper sulphate and zinc chloride retarded the rate of seed sprouting during the first year, but the zinc sulphate accelerated germination. All of the salts, but particularly the zinc chloride, slightly increased the number of germinations that were delayed for a whole year. More important than any of these phenomena, however, was the relative extent of fatal injury to growing root tips. In this respect copper sulphate was most harmful, the zinc chloride next, and the zinc sulphate least harmful.

With these general tendencies in mind, an effort was made to select the best treatment from among those which produced no root injury; that is, zinc sulphate at the rates of 4 to 8 grams and zinc chloride at the rates of 4 and 6 grams per square foot. The two zinc chloride treatments were much alike in showing a tendency to reduce the germinative energy of western white pine seed, and were nearly equal in the total tree-seed germination attained; but the 6-gram application was the more effective on weeds. Of the three zinc sulphate treatments in question, all greatly reduced the sprouting of weed seed, the 4-gram application being least effective. All three, but especially the 8-gram application, stimulated the germinative energy and increased the total number of western white pine seeds that emerged from the soil.

Thus, slight advantages narrowed the choice down to two applications—the 8-gram zinc sulphate and the 6-gram zinc chloride treatments. Of these, the latter seemed to be the more effective on weeds, but gave a slightly smaller total number of pine seedlings and failed to hasten pine germination as did the former. Also, the data in Figure 1 suggest that, if through any cause as much as 2 grams more of the chemical than was intended be applied per square foot, greater injury might be expected to result from the 6-gram zinc chloride than from the 8-gram zinc sulphate treatment. The safe and the fatal limits of concentration of these salts were not determined with sufficient precision to establish this point with certainty, but the possibility of extensive damage resulting from irregularities in distribution of the chemical in large-scale treatments had to be considered. The relative cost of these two materials per unit weight of zinc was almost the same at central markets, but freight rates on the sulphate were about twice those on the chloride. On the other hand, zinc chloride is a fused and completely dehydrated salt and hence more hygroscopic and difficult to handle in the nursery than is zinc sulphate. Consequently the 8-gram zinc sulphate treatment was selected as the best.[7]

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[7] The comparison here of the relative effects of the sulphate and chloride of zinc may appear unscientific because no direct comparisons were made of doses containing chemically equivalent amounts of zinc. This was an oversight in the plans for the work and can not well be adjusted in any way in interpretation of the original data. The author freely admits that because of this weakness in the original plan, the evidence on which zinc sulphate was selected rather than zinc chloride is not convincing. No practical case has been made against the chloride and further research might easily indicate equality or even superiority for the chloride. An attempt is made merely to show the line of thought, possibly a faulty one, whereby the sulphate was singled out for further study.

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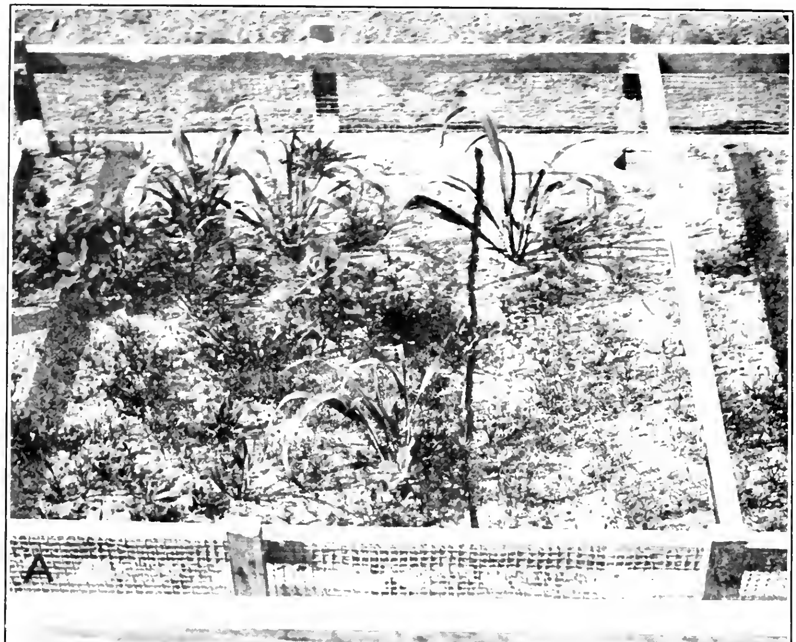
EFFECT OF ZINC SULPHATE TREATMENT

A.—Left, the 6-gram plot; right, the 4-gram plot.
B.—Left, the 10-gram plot; right, the 8-gram plot.
C.—Left, the check plot that received no treatment; right, the 12-gram plot.



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EFFECT OF ZINC SULPHATE TREATMENT

A. Right, western yellow pine the first year after treatment with 8 grams of zinc sulphate; left, similar plot not treated.
B. Field peas sown for green fertilizer one year after treatment, showing satisfactory results on both treated and untreated plots.

It was planned to obtain information on the survival of seedlings from treated plots to substantiate this choice. An early and unexpected snow cover in the fall of 1919 prevented detailed counts in the plots at that time but general observations and photographs were made. Plate 2 shows how the series of zinc sulphate plots appeared. The duplicate series checked very closely with the one illustrated here, particularly in regard to the clean eradication of weeds in the 8-gram plot. The relatively better stand of pine in this plot than in those of stronger treatment agrees with the figures showing that root injury to pine seedlings first became apparent in the 10-gram plot. (Table 2.)

TEST OF 8-GRAM ZINC SULPHATE TREATMENT ON TWO SPECIES OF PINE

In the fall of 1919 and the spring of 1920, 16 test plots of 12 square feet each were established. This time only the 8-gram zinc sulphate treatment was applied, but another tree species was introduced, the western yellow pine. As in the earlier tests, there was a marked reduction in the number of weed seeds that sprouted.

Four treated plots and four untreated plots were each sown in the fall of 1919 with 1,000 seeds of clover. Similar groups of four plots were sown in the same way with sorrel and timothy seed. During 1920 the following germinations occurred, the figures being the average number on each group of four like plots:

	Treated	Untreated
Clover	0	49
Sorrel	0	26
Timothy	0.5	86
Volunteer weeds	1	64
Total	1.5	225

Thus with the same sowing treatment 225 weed seedlings came in on untreated soil and only 1.5 on treated soil. The germinations the following year from viable seeds remaining in the soil and from seeds having been subsequently sown by natural means in these unprotected plots were 2 on treated soil and 21 on untreated soil.

Very similar effects on weed growth were observed from the treatment of duplicate plots in the spring of 1920. No samples of weed seed were artificially sown in these tests but the treated and untreated soil was given equal exposure to natural seeding. During the season the average results from duplicate plots were as follows:

	Treated	Untreated
Clover	0	47
Sorrel	0	19
Timothy	0.5	38
Other weeds	0	19
Total	0.5	123

How these plots appeared at the end of their first season is shown in Plate 3, A. That this relative freedom from weeds on treated soil may be expected to change very little during the second season is indicated by the tests already reported.

It is important to note that the otherwise very satisfactory persistence of toxic effects in the soil during the second year as a result of this chemical treatment seems to be reduced or eliminated if the soil be disturbed. In 1921 many weeds appeared during the summer in scattered places where the soil had been disturbed by the use of a spading fork and the pulling out of the tree seedlings. It may be that in undisturbed plots capillary movement of the soil solution has in some way maintained a higher concentration of the toxic solute at the surface, which forms the germinating medium for seeds, than at deeper levels, and that pulling trees has abruptly destroyed such a condition. Further observation of this phenomenon is needed.

The effects of the zinc-sulphate method on pine seedlings in nursery beds as indicated by these trials are given in Table 5.

Table 5.—*Germination, loss, and survival of western white and western yellow pine grown in soil treated with 8 grams of zinc sulphate per square foot*[1]

GERMINATION AND SURVIVAL

Species and plots (1919)	Germination				Survival in 1920	
	1920	1921		Total		
	Number	*Number*	*Per cent*	*Number*	*Number*	*Per cent*
Western white pine:						
Treated plots	664	10	1.5	674	259	39.0
Untreated plots	532	28	5	560	199	37.4
Western yellow pine:						
Treated plots	572	0	0	572	434	75.9
Untreated plots	501	1	.2	502	371	74.1

LOSSES BY CAUSES, 1920

Species and plots	Fungus	Cut-worms	Drought	Miscel-laneous
	Per cent	*Per cent*	*Per cent*	*Per cent*
Western white pine:				
Treated plots	41.5	53.1	0.7	4.7
Untreated plots	12.0	80.5	.3	7.2
Western yellow pine:				
Treated plots	57.2	23.2	7.3	12.3
Untreated plots	46.9	32.3	1.5	19.3

[1] Seed beds were sown in the fall of 1919. Figures are averages based on 3 plots sown with 1,000 seeds each. They may be converted into percentage figures based on the number of seeds sown by merely pointing off 1 decimal place. Percentage figures listed in the "germination" section of the table are based on total germination, in the "survival" section on the first-year germination, and in the "loss" section on loss in 1920.

It is important that certain weaknesses in the basic data be explained. An attempt was made to list all fatalities according to the most apparent or major cause of death. Chemical injury is not mentioned in the table as a cause of mortality, because, as in similar tests of the same quantity of zinc in earlier experiments, no positive evidence of the existence of such injury was found. However, the difficulty of distinguishing between deaths from drought, damping-off, and chemical injury at this stage in the life of seedlings may have resulted in inaccurate classification of causes of loss. Chemical injury may, indeed, have been an important contributory cause of death of some seedlings. For example, contrary to expectation, relatively more trees seemed to have been lost from fungous trouble on the treated soil. Even if this observation could be regarded as accurate, it has little significance because it was based on a single trial. Like the smaller ravage from cutworms on treated soil, it may well have been accidental and could not be depended upon to recur.

The element of chance of infection by fungus or infestation by insects may easily outweigh the effects of any special susceptibility to injury. In other words, lack of control has made it impossible to trace these effects to their causes on so small a basis of observation. For similar reasons the relation of the chemical treatment to hold-over germinations can not be definitely stated. The slight tendency of zinc sulphate, evident in the first tests, to increase second-season sprouting of western white pine seeds was not in evidence in 1921. Had the results of water cultures with zinc sulphate been available, they might have aided in the explanation of some of these points by providing a better conception of the relative tolerance of dormant seeds and of growing roots to different quantities of the poison. Such fundamental points as these deserve further investigation.

The zinc-sulphate tests, however, gave some definite results, which are recorded in Table 5. As a result of the treatment, the number of seeds of western white pine sprouting during the first season was increased by 25 per cent, through control of parasites or other means, and of western yellow pine by 14 per cent. The percentage of survival, based on the total number of seedlings emerging from the soil during the first season, was not appreciably affected by the treatment, being for each species about 2 per cent higher in the treated soil. In other words, the rates of loss did not differ greatly in the treated and untreated soil.

In general the results of the zinc-sulphate tests served to corroborate the results of the first series and yielded two additional points of interest. These were that the treatment appeared to be as harmless to yellow as to white pine, and that artificial disturbance of the soil seemed to reduce greatly the latent toxic action of zinc sulphate. This effect of soil disturbance might cause the chemical treatment to be ineffective in transplant fields where the trees are cultivated; but it would in no way lessen the value of such chemical methods when used on seed beds that are not cultivated during the life of the crop. This observation suggests, however, the necessity of a new application of salt to seed beds for each new crop of trees.

OTHER EFFECTS OF THE SOIL TREATMENT

Among the questions that remain to be answered are the following: What is the effect of chemical treatment on the field-pea plants used as a soiling crop? What is the effect on subsequent development and survival of the pines and on other kinds of trees such as spruce and cedar? Will this treatment be useful on transplant beds? What precautions are necessary to successful application of the method? Will it work on freshly fertilized soil? While holding the amount of salt per square foot constant during any one treatment, is it safe to reduce the amount of water used, thus increasing the concentration of solution? Lastly, there arises the fundemental question of the cumulative effects on the soil of repeated doses of salt over the same areas. These questions, in whole or in part, were answered by further experiments.

EFFECT ON FIELD PEAS

Despite its promise of becoming an efficient means of reducing weed growth, the chemical treatment of the soil would be impracticable if it were to prevent the growing of green fertilizers. It was natural to expect such difficulty because the zinc sulphate had so effectively eliminated the sprouting of so many miscellaneous weeds, including clover, a leguminous plant.

In the spring of 1921 a crop of field peas, the usual soiling crop at Savenac nursery, was sown on untreated plots and on similar plots which had received the soil treatment just one year previously and had supported a crop of western yellow pine during its first season. The seeds were uniformly broadcast and covered with sand. Germination was prompt and uniform in all plots. Apparently most of the seeds which were sown germinated on treated as well as on untreated soil. (Pl. 3, B.) No water was applied until the dry season started. Growth was equally rapid in the plots and no unhealthly color of any significance was observed in the foliage. At the close of the season two sample areas were selected, the roots of the plants washed out of the soil, and the plants removed for laboratory examination. Counts showed nearly half again as many pea plants per square foot on treated soil as on untreated soil, indicating better germination of seeds under treatment. The resultant crowding and poorer development of plants on treated soil is not regarded as significant because the plants are unimportant individually. Oven-dry weights in grams of the mass of plant material per square foot were as follows:

TABLE 6.—*Oven-dry weight per square foot of field peas grown on treated and on untreated soil*

Method	Tops	Roots	Nitrogen nodules	Total
	Grams	*Grams*	*Gram*	*Grams*
Treated	80.52	6.28	0.63	87.43
Untreated	81.09	3.91	.47	85.47

The following year another crop of peas was grown on the same plots with equal success. Growth and development of the plants on the treated soil seemed about the same as on the untreated checks, but the foliage was slightly darker green, owing, perhaps, to somewhat greater increases in available nitrogen on treated soil as a result of the previous crop.

The top-root ratios of peas are not of so much interest as are those of trees for field planting, because with peas the main consideration is vegetative matter for the production of humus. The relatively heavier root systems of the peas found in treated soil correspond to results of work by Reimer and Tartar (*34*) indicating that various sulphur fertilizers doubled or trebled the size of alfalfa root systems, and with the findings of Hart and Tottingham (*17*) or Pitz (*32*) that calcium sulphate increased the root development of clover. Although the development of more nitrogen nodules with peas on treated than on untreated soil at Savenac nursery is contrary to the results obtained by Wilson (*42*) and Fellers (*13*) that zinc sulphate as well as calcium sulphate and ferric sulphate depressed nodule formation on soybeans, the finding seems to be supported by the work of Miller (*29*) and Dudley (*11*) with clover.

It might be argued on the basis of such reports as that of Brenchley (*4*) that the favorable results obtained at Savenac nursery with the experiment on peas could be explained solely on the basis of the varying sensitiveness of different plants to zinc poisoning. However, a later test at Savenac confutes this contention. In this test, in which zinc sulphate was applied immediately after the sowing of peas, the sprouting of all seeds, including peas, was almost completely prevented. The loss of poison by leaching or other means when the soil was disturbed by uprooting pine seedlings is the suggested cause of success in the first experiment with peas.

DEVELOPMENT OF PINE TREES FOLLOWING SOIL TREATMENT

Good development of trees in the nursery results in high quality of planting stock and consequently in better chances for survival and more rapid early growth in forest plantations. It is essential, therefore, to study the effect of chemical treatment on the development of trees.

A comparison of averages from various measurements of seedlings is given in Table 7. The trees on which these measurements were taken were mechanically selected by counting out every fifth plant from stock which had been lifted from the nursery and root pruned for transplanting or field planting. As none of the trees were crowded in the seed beds, disturbing influences from variations in density were considered negligible. The measurements sought especially to detect any inferiority of the seedlings from treated soil. The apparent superiority of some of these seedlings may have been caused, at least in part, by the lack of competition with weeds rather than by any direct stimulation from the chemical.

TABLE 7.—*Effect of treated versus untreated soil on the growth and development of pine seedling stock*[1]

Species, age, and condition of seed bed	Length of stem	Diameter of stem at ground	Lateral rootlets				Oven-dry weight of plant	Proportionate weight		Length of needles	Needles measured
			Primary		Secondary						
			½ to 2 inches	Over 2 inches	½ to 2 inches	Over 2 inches		Top	Root		
Western yellow pine:	*In.*	*Millimeters*	*Number*	*Number*	*Number*	*Number*	*Grams*	*Per cent*	*Per cent*	*In.*	*Number*
1-year seedlings—											
On treated soil	2.41	1.35	7.26	0.95	0.56	0	0.2274	58.0	42.0	0.91	50
On untreated soil	2.24	1.33	8.90	1.28	.08	0	.2272	59.3	40.7	.87	50
2-year seedlings—											
On treated soil	4.56	2.27	11.47	2.54	.64	.01	1.122	83.1	16.9	1.96	57
On untreated soil	4.15	1.72	12.31	1.91	.31	0	.626	80.2	19.8	1.53	54
Western white pine:											
2-year seedlings—											
On treated soil	2.22	1.46	8.45	1.66	.27	0	.284	61.6	38.4	.84	55
On untreated soil	1.98	1.28	7.92	.73	.05	0	.208	59.6	40.4	.76	56

[1] Measurements of 1-year stock (1–0) are averages of 100 representative seedlings in each instance; for 2-year stock (2–0) 110 seedlings were used for length measurements and 100 for weight measurements.

Before interpreting the figures in Table 7, the purpose and the limitations of these figures should be more clearly defined. The general purpose, of course, is the detection of possible differences in plant development due to the chemical treatment of the soil, differences that might not be discernible except in the average measurements of 100 or more plants. The particular purpose is to show differences in what is called balance or the top-root ratio. Balance is the ratio between the capacity of the top to transpire moisture and the capacity of the root to absorb moisture. This ratio can not be directly measured and must be approximated. Although a comparison of the oven-dry weight of tops and roots is inexact as a measure of balance, mainly because volume of wood, which directly affects weight, has no influence on the transpiration-absorption ratio; still, it is the most practical method of getting an approximation of true balance in small plants containing but little wood. The method of counting the number of roots falling into certain length classes yields figures which are also imperfect as a measure of root development, principally because the small rootlets less than 0.5 inch long were disregarded entirely. Although these limitations reduce the precision of the work, the figures still give a better basis for comparisons than can be had from superficial observation.

Table 7 indicates that 1-year-old western yellow pine trees from treated soil compare very favorably with similar trees from untreated soil, except possibly in number of rootlets (primary and secondary). In this respect the untreated trees averaged 15 per cent more rootlets in the short length class and 35 per cent more in the longer class than the treated trees. Because of this and because of the slightly shorter tops of trees from untreated soil, it would be expected that the top-root ratio by weight would be greater for the treated stock, but actually it was slightly less. The discrepancy can only be explained on the basis of what has already been said of the imperfections in methods. The root differences noticed suggest that zinc sulphate in the soil solution, even though too weak to cause visible injury to root tips, retarded the growth of roots. The persistence of such retardation of root growth might well be expected to result in similar reduction in the later growth of tops and in general loss of plant vigor. Largely because this did not happen, the root differences just described were not considered to be serious.

A year later samples from the same lot of trees which were then 2–0 [8] western yellow pines, showed what might be interpreted as complete recovery from early symptoms of indisposition. All measured characters, except balance, yielded more favorable figures for the stock from treated soil than for that from untreated soil. (Table 7.) The 34 per cent more rootlets (primary and secondary) in the greater length class for trees from treated soil much more than offset, in value to the trees, the 4 per cent advantage in number of short rootlets belonging to the trees from untreated soil. The treated lot of stock consisted of somewhat taller, sturdier, better-rooted, and generally better-developed trees than the untreated lot.

That the trees from treated soil had 3 per cent more of their total plant weight contained in the tops was not in their favor but was probably due merely to the artificial pruning operation which pre-

[8] As readers familiar with nursery practice will know, this terminology indicates the number of years spent by the plant in the seed bed and in the transplant bed. For example, 2–0 stock are seedlings 2 years old used in the field without previous transplanting, and 2–2 stock has been two years in the seed bed and two years in the transplant bed. Similarly, 1–2 stock and 2–1 stock are both 3 years old, the former having been transplanted at 1 year of age, the latter at 2 years.

ceded the measurements. In this operation all roots more than 6 inches from the ground line were pruned off, thus favoring the smaller plants by the removal of a smaller portion of their total root system.[9] The difference is not, however, great enough to be significant in field survival, and furthermore in similar 2–0 stock examined a year later it failed to appear.

The effects of treated soil on the development of western yellow pine seedlings hold also for western white pine, as is shown (Table 7) by the larger average measurements for the trees grown on treated soil. In other words, treated soil has been as favorable to the development of 2-year-old western white pine as it was to similar western yellow pine seedlings.

The same trees were further observed after removal from treated seed-bed soil to the untreated soil in transplant beds. The western yellow pine stock was transplanted in the spring of 1921 and the western white pine a year later. A comparison of the stock from the two kinds of soil and at different ages is shown in Table 8.

TABLE 8.—*Latent effect on transplants of origin in treated versus untreated seed beds*[1]

Kind of stock and condition of seed bed	Seedlings trans-planted	Thrifty	Un-thrifty	Injured	Missing	Dead
	Number	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
1-1 western yellow pine:						
From treated soil	392	71.1	25.5	2.8	0.3	0.3
From untreated soil	400	66.8	25.8	2.0	.7	[2] 4.7
1-2 western yellow pine:						
From treated soil	400	86.8	12.8	0	.2	.2
From untreated soil	400	85.0	8.5	0	6.3	.2
2-1 western white pine:						
From treated soil	577	81.8	17.3	0	.5	.4
From untreated soil	583	83.4	15.4	0	0	1.2

[1] These figures record the result of observations on western yellow pine transplants 1 year after transplanting (1-1 stock), and the same trees a year later (1-2 stock).
[2] Six out of nineteen trees died from injury by a garden hose to which the plants of the treated lot were not subjected.

There seems to have been little evidence of difference in the stock which could be attributed to chemical action. The lots appeared to be in very similar good condition. The only possibly unfavorable sign was the presence among the western white pines of a few more unthrifty trees from treated than from untreated soil, but the difference was hardly sufficient to be significant, and, as will be shown later, it did not persist in the field plantation. For views of transplant rows of this stock see Plate 4, A and B.

For the purpose of observing the relative survival and development of stock in the field, some 3,500 trees from treated and untreated nursery soil were planted by the slit method in 1922 and 1923. In May, 1922, two plantations of 2–0 seedlings were made, one of about 800 western yellow pine on a southeast slope, and the other of an equal number of western white pine on a northwest slope. On the same sites in the spring of 1923 about 1,140 (2–1) western white pines and about 750 (1–2) western yellow pines were planted.

[9] At the time the work was done it was desired to disregard all root development below 6 inches because it would be pruned off in any case in actual planting practice. Since then the planting crews have been planting longer roots in deeper holes, so that were this experiment repeated using the improved methods now in vogue, the slightly superior balance of stock from untreated soil might no longer be in evidence.

The comparative development of the seedling stock planted in 1922 has been considered in detail in Table 7. No laboratory study was made of the transplants set out in 1923. Previous to planting, the western white pine transplants were root pruned in bunches of 50 at a point 6.5 inches from the ground line. The western yellow pines were pruned in bunches of 25 to an 8-inch root length.[10] This removed from 4 to 8 inches of roots from one-third of the number and half as much from the remaining trees. From the appearance of the roots in bunches the plants from treated soil seemed to have a slightly larger number of lateral rootlets.

Trees from treated and untreated soil were set in alternate rows in the field in order to equalize their exposure to slight variations in soil and competing vegetation. Every tree planted in each of the four plantations was marked individually with a lath stake painted white. This facilitated the taking of accurate field notes on the behavior of the trees during the next three years. The plantations were examined monthly during their first season and in the spring and fall of the second and third years.

TABLE 9.—*Latent effect on field-planted seedlings and transplants of origin in treated and untreated seed beds*[1]

Stock planted, year of planting, and condition of seed bed	Thrifty	Unthrifty	Dead
Western white pine:			
2–0 stock, planted 1922—	*Per cent*	*Per cent*	*Per cent*
From treated soil	55.0	1.3	43.7
From untreated soil	50.0	1.0	49.0
2–1 stock, planted 1923—			
From treated soil	93.5	.9	5.6
From untreated soil	95.6	.9	3.5
Western yellow pine:			
2–0 stock, planted 1922—			
From treated soil	16.2	0	83.8
From untreated soil	19.5	.5	80.0
1–2 stock, planted 1923—			
From treated soil	77.2	3.1	19.7
From untreated soil	79.9	1.7	18.4

[1] Figures are percentages of the number planted—400 or more in each lot, 3,490 in all.

The results were watched with interest because it was thought that the treated soil might have caused some injury that escaped detection in the nursery observations and laboratory studies. By September of the first year the majority of the unthrifty plants had either died or recovered and by the third year the losses in all plantations were small. The condition of the trees in the fall of their third field season is shown in Table 9, and stages by which this degree of survival was attained are shown graphically in Figure 3. The differences in survival between plantations were marked, the transplants being superior to the seedlings and the site on which the western white pine was planted being more favorable to plant life than that on which the western yellow pine was planted, but for each class of stock the survival trends were very similar and differences in survival were too small to be significant when some allowance is made for experimental error. The 2–0 western white pine stock

[10] Numerous seedlings in a bunch may be quickly and satisfactorily root pruned at one stroke if the plants themselves are small. When large and bushy seedlings are pruned in this way the plants on the interior of the bunch are cut shorter than the others. Because the western yellow pines were larger than the western white pines in this experiment fewer plants could be uniformly pruned at once.

from treated soil was 5 per cent higher in survival than that from untreated soil, but for each of the other classes of stock the trees from untreated soil survived best by amounts from 1 to 4 per cent.

In the fall of 1925 after the transplants had been three years in the field, measurements were made of total height and of the length of the growth made by terminal shoots during the year. No attempt was made to select trees for measurement except that all injured, abnormal, or very unthrifty plants were excluded. The results are given in Table 10.

TABLE 10.—*Height growth in the field three years after planting of trees from treated versus untreated nursery soil*

Kind of stock and condition of seed bed	Total height	1925 growth	Basis, trees
	Inches	*Inches*	*Number*
Western white pine, 2-1 stock:			
From treated soil	5.1	1.2	301
From untreated soil	5.1	1.2	302
Western yellow pine, 1-2 stock:			
From treated soil	7.8	2.0	200
From untreated soil	7.3	1.6	200

From the observations made, it appears that the survival and development of pines from treated and untreated nursery soil are very similar.

EFFECT ON TREE SPECIES OTHER THAN PINE

Pines only were used in the experiments so far described. In the spring of 1922 two plots sown to Engelmann spruce, (*Picea engelmannii*), and two to western red cedar (*Thuja plicata*) were given zinc sulphate treatment. The behavior of these plots during the season is shown by Tables 11 and 12. The small difference in survival of spruce on the two soils is considered to be within the limits of experimental error and not significant, but cedar showed lower germination and greater loss on treated soil at each count and resulted in less than half the survival obtained on untreated soil. It seems probable either that the thin seed coats of western red cedar were more easily penetrated by the zinc poison or that the cedar is less tolerant of zinc than are other conifers. The usual effect of practically complete elimination of weeds was attained on treated soil. Four of these plots are shown in Plate 4, C.

TABLE 11.—*First-year germination of Engelmann spruce and western red cedar under 8-gram zinc sulphate treatment* [1]

Species and treatment, 1922	June 16	June 27	July 7	July 18	July 29	August 17
	Number	*Number*	*Number*	*Number*	*Number*	*Number*
Engelmann spruce:						
Treated plots	66	58	25	21	7	11
Untreated plots	86	42	13	20	7	11
Western red cedar:						
Treated plots			132	40	5	0
Untreated plots			179	77	10	0

[1] Each figure represents an average number of seedlings for two plots sown with 500 seeds each. *Picea engelmannii* (Lolo National Forest), seed sown May 24, 1922, and *Thuja plicata* (Lolo National Forest), seed sown June 7, 1922. Soil treated with 8 grams zinc sulphate per square foot.

TABLE 12.—*First-year survival and losses of Engelmann spruce and western red cedar under 8-gram zinc sulphate treatment*

Species and treatment, 1922	Survival			Losses from—		
	Seedlings	Based on seed sown	Based on germination	Fungus	Cutworms	Miscellaneous
	Number	*Per cent*	*Per cent*	*Number*	*Number*	*Number*
Engelmann spruce:						
Treated plots	133	26.6	70.7	15	21	19
Untreated plots	149	29.8	83.2	11	11	8
Western red cedar:						
Treated plots	113	22.6	63.8	20	0	44
Untreated plots	246	49.2	92.5	12	1	7

In the fall of the same year a similar test was made with Douglas fir seed. During 1923 the plots received no attention except sprinkling, the weeds being allowed to run riot on the untreated soil. In the fall there were 174 fir seedlings on treated soil as compared with 53 on the untreated soil where they had to compete with weeds, a reduction of 70 per cent on the untreated soil.

These tests were neither so intensive nor were they followed so long as the experiments with pine, but as far as they go the indication is that the chemical treatment may be used with spruce and Douglas fir but not with cedar.

The use of zinc sulphate as a soil treatment was not tested in seed beds of any other species of trees at Savenac nursery, but Darnfelt (*9*), after visiting the nursery in 1924, experimented with *Pinus sylvestris* and *Picea excelsa* in Sweden. He reports no damage to these species from the zinc treatment. In a later paper Darnfelt (*10*) describes further encouraging results from his experiments. He used zinc sulphate at the rate of 60 grams per square meter dissolved in 2.5 to 5 liters of water, and obtained reductions of 50 to 75 per cent in weed growth.

DANGER TO THE SOIL

Some observations made in Germany in the latter part of the nineteenth century are worth recording here because of their direct bearing on the present problem. Sorauer (*38, p. 752*) reports that Konig (*25*) paid especial attention to the effects of waste waters containing zinc sulphate from zinc blend mines. Streams receiving such water were found to contain zinc oxide in solution, and to cause an evident retrogression in the yield on meadows they watered; even in places a very poor growth. Up to 2.78 per cent of the ash of grasses grown on such sterile places, as well as the deformed, bushy beech and maple trees, was zinc, whereas the ash of normal meadow plants contained none of this metal. Only one specific zinc plant, the "white mineral blossom," was found It contained not less than 11 per cent of zinc oxide in its ash. Two points were brought out, (1) the great difference in the susceptibility of different plants to injury and the high concentrations that sometimes may be endured, and (2) the fact that injury occurred only after a number of years during which the zinc had accumulated from water containing only very small quantities in solution.

The possibility of serious injury to the soil as a result of repeated chemical treatment was recognized early in this work. In 1921 Kelley [11] warned that soil injury might well be expected for two reasons, (1) because zinc in any considerable concentration is a definitely established plant toxin to which different species are susceptible in various degrees; and (2) because zinc sulphate, being a salt of a weak base and a strong acid, will tend to produce acidity in the soil. Other students of plant nutrition doubted if the Savenac treatments would result in sufficient quantities of zinc in the soil at any one time to be injurious to the tree crops and were inclined to believe that injurious acidity would not develop in the near future.

The tendency for sulphur to produce soil acidity, however, has been observed by numerous investigators. Storp (*39*) states that the presence of zinc generates free sulphuric acid in some soils. Olson and St. John (*31*) quote 12 authors who agree that sulphur in various forms increases soil acidity. The relation of acidity in the soil to the metabolism of plants is not thoroughly understood as yet, but coniferous trees are often thought of as preferring acid soil. Wherry (*41*) lists certain coniferous forest trees as preferring acid habitats, although also occurring on soils of intermediate reaction such as other conifers appeared to prefer. Experiments reported by Baker (*2*) indicate that unless acidity or alkalinity reach extreme points they do not limit the survival or growth of western yellow pine. Physical character of the soil had a greater influence on the trees than soil acidity. Other investigators have concerned themselves with the effect of an acid state on soil fertility through the influence of hydrogen ions on nitrogen fixation by certain soil organisms. Meek and Lipman (*28*) observed that, although nitrification proceeded in peat soil of low pH value, organisms from garden soil ceased the production of both nitrites and nitrates at pH values below 5.4. The same men, in studying the resistance of nitrifying bacteria to high salt concentrations, found that the sulphate was less toxic than other sodium salts. As has been pointed out in the present study, zinc sulphate in a single test seemed actually to stimulate the production of nodules on the roots of field peas. The chances for the development of unfavorable soil conditions from the use of zinc sulphate, however, are sufficient to warrant constant vigilance.

In 1924 numerous unthrifty 1-year-old western white pine seedlings were found in one of the principal fields at Savenac nursery. The soil had been treated with zinc sulphate and showed a slightly unnatural color. When the soil surface was air-dry and neighboring untreated soil was light colored, the treated soil appeared darker, as if it were moist. These observations, particularly the unthrifty condition of the trees, brought about a soil-acidity survey by the author, a field inspection by a representative of the Bureau of Soils, and soil examinations in the laboratories of that bureau. The findings of these three agencies agreed that both treated and untreated soils were strongly acid, having an average pH value of about 5.3.

[11] Kelly, W. P., in a personal letter to the author from the agricultural experiment station, University of California, Berkeley, Calif.

but that as yet this condition showed no connection with the zinc sulphate treatment.

The treated soil in question had received but one application of zinc sulphate and was no more acid than the surrounding untreated soil. Acidity seemed rather to have been caused by irrigation with slightly acid water and by the presence of a somewhat impervious subsoil. The unnatural color of the air-dry soil is attributed to a film of actual moisture on the surface of soil particles and pebbles, due to the hygroscopicity of the salt. Meanwhile the unthrifty color of the foliage on the seedlings disappeared. The next year the trees on treated soil had developed equally well with those on untreated soil and had apparently recovered completely. The investigation did not reveal the cause of the temporary unthrifty appearance of the trees, but it served to remove the suspicion that soil acidity resulting from zinc sulphate treatment was the cause of unthriftiness. Thus the first dose of zinc seemed to have been as harmless in these large-scale trials as it proved to be in the earlier small experimental plots.

In order to estimate the possible injury from a second dose of zinc, an attempt was made to determine the quantity of the first application still remaining within reach of the tree roots. The Forest Products Laboratory at Madison, Wis., tested samples and found no soluble zinc in the untreated soil or in the treated soil two years after the application. In the treated soil 0.30 per cent of insoluble zinc [12] was found. Similarly no soluble zinc was found in the ashes of either white or yellow pine from treated or untreated soil. This was to be expected because wood ashes are so strongly alkaline with potassium carbonate that the soluble zinc would be precipitated as insoluble zinc carbonate. In the ashes of western white pine from treated soil 0.48 per cent of insoluble zinc was found and in the ashes of western yellow pine from treated soil 0.50 per cent. None was found in tree ashes from untreated soil. Thus it seems that soluble zinc had entirely disappeared from the soil in two years, and that which was not lost through leaching was either absorbed by the trees or deposited in insoluble form in the soil.

The possibility of some of this insoluble zinc again becoming soluble, either through the action of the roots themselves or other compounds such as ammonium salts, suggested that reduction in the amount of zinc sulphate applied the second time might be advisable. Second treatments were tried in 1924 on plots which had been given the standard treatment for the first time in 1922. In preparing the soil the land was plowed in 1922, but spaded in 1924 in order to keep the same mass of soil for second treatments. Results are given in Table 12.

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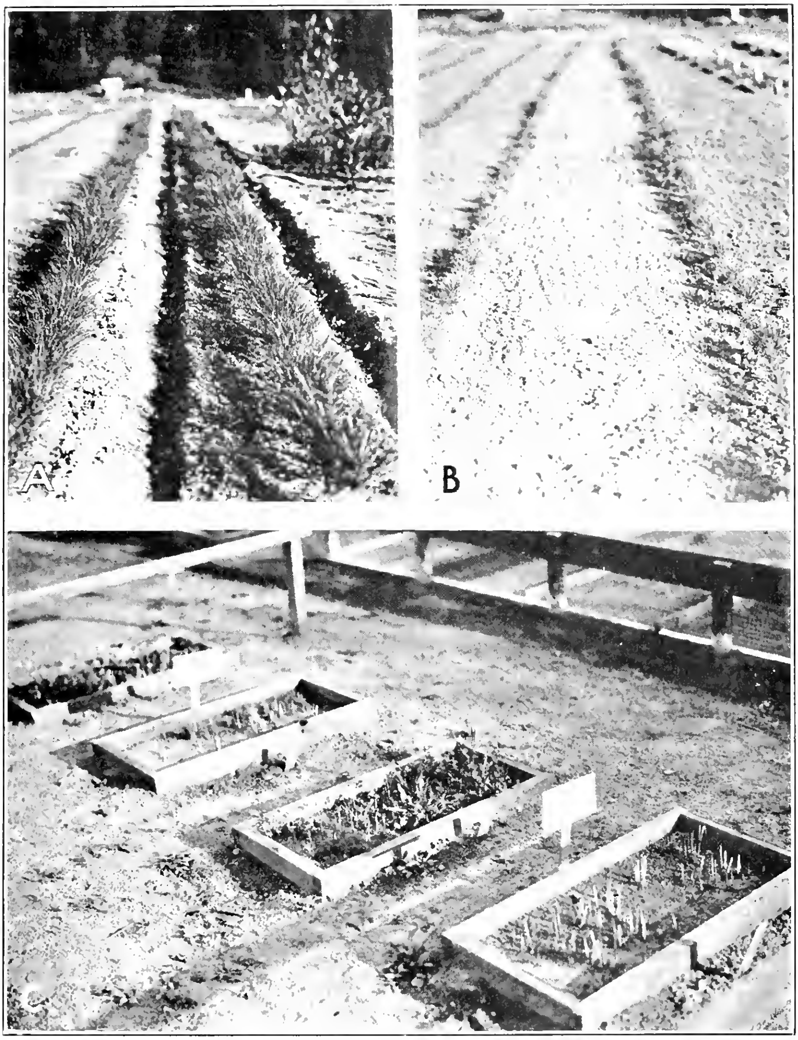
[12] The chemical state of this insoluble zinc was not determined. It is believed to have been the oxide or possibly the carbonate. The quantity was determined by dissolving in acid and calculating back to the original chemical used. Soil samples were composites made up from soil taken at various points throughout the root zone of the nursery trees.



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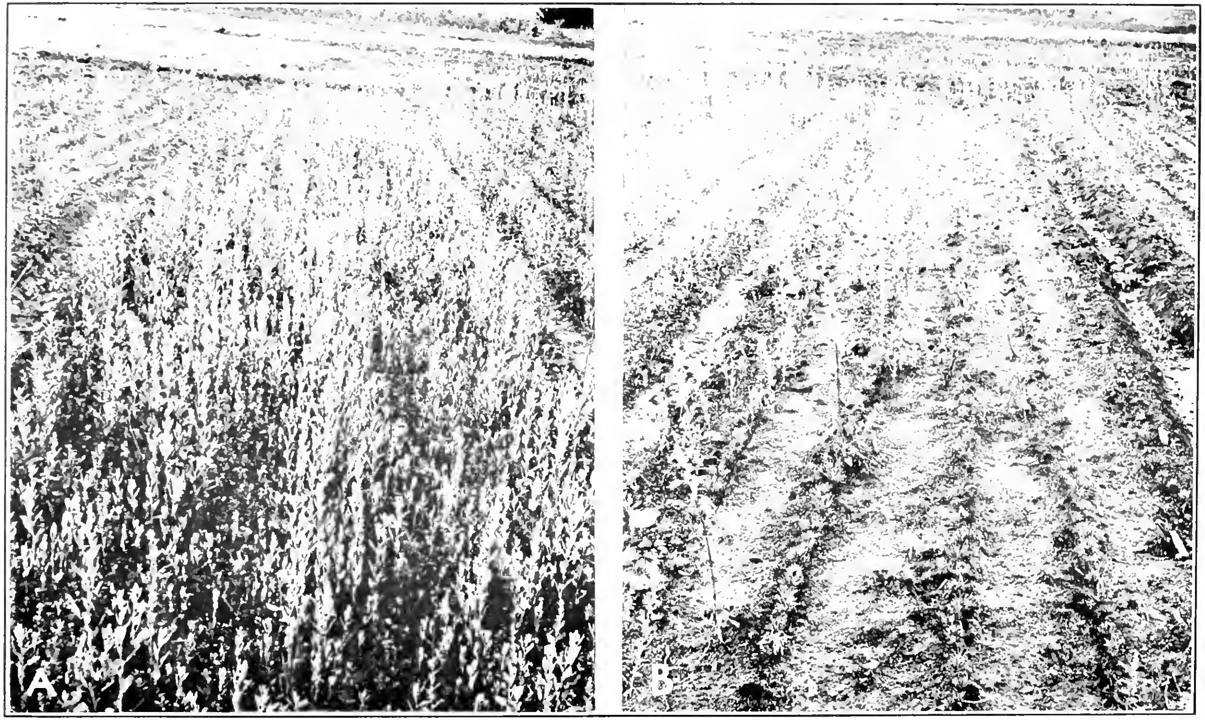
TREATED V. UNTREATED PLOTS OF THREE SPECIES

A.—Left, 1-2 western yellow pine from treated soil; right, same stock from untreated soil.
B.—Right, 2-1 western white pine from treated soil; left, same stock and from untreated soil. The irrigation ditches appearing as dark streaks in A have been filled in in B.
C.—Engelmann spruce plots, showing in the treated plots, marked "T," absence of weeds and toothpicks marking small spruce seedlings.



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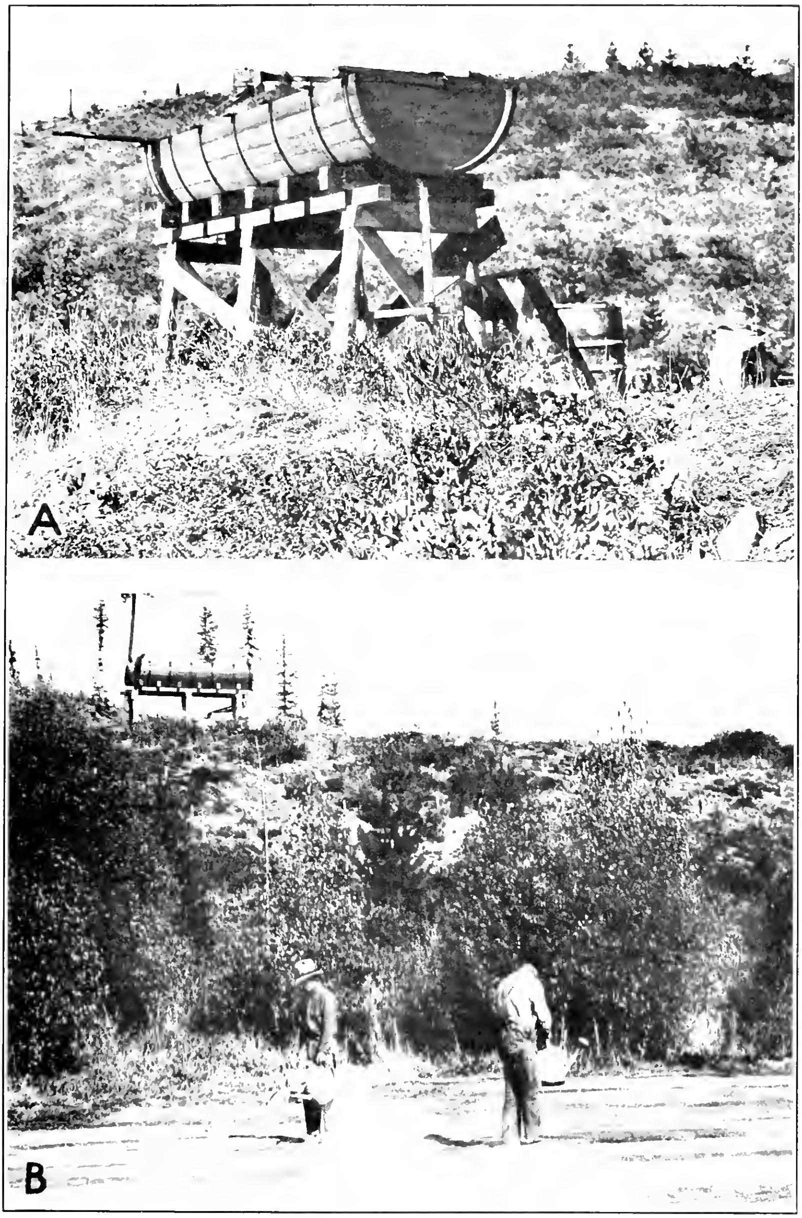
EFFECT OF TREATMENT IN TRANSPLANT BEDS

A.—Untreated transplant bed of 4-0 Engelmann spruce showing rank growth of cotton cudweed (*Gnaphalium palustre*) after three months.
B.—Transplant bed of 1-0 western white pine, three months after planting and treatment with 12 grams of zinc sulphate per square foot. Scattered lamb's-quarters (*Chenopodium album*) are conspicuous because of size rather than number. Survival of the pine under this heavy treatment was 77 per cent as against 88 per cent without treatment.



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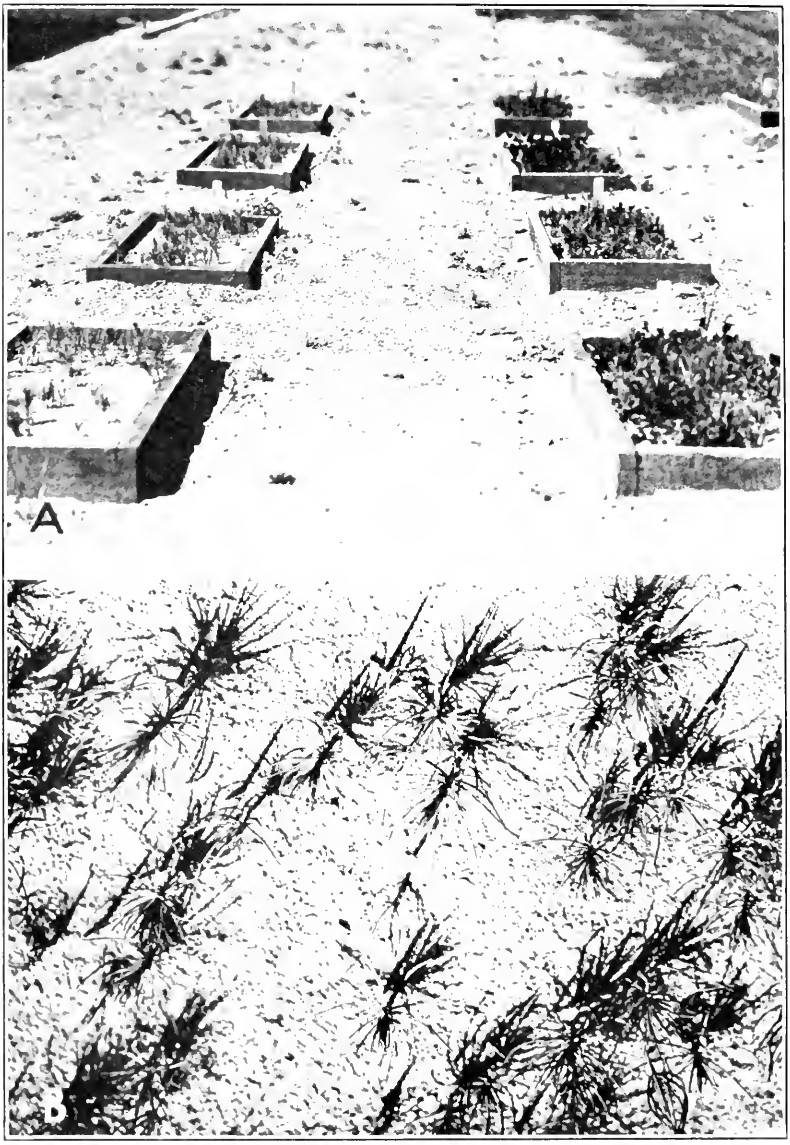
METHOD OF LARGE SCALE TREATMENT

The zinc sulphate solution drawn from an elevated tank (A) is distributed evenly on newly sown seed beds (B), with ordinary sprinkling cans.



F-168825-168826

EFFECT OF TREATMENT WITH 8 GRAMS OF ZINC SULPHATE PER SQUARE FOOT

The contrast (A) between treated plots (left) of 1-0 western yellow pine and untreated (right) is further emphasized by a closer, downward view (B) of one of the treated plots, showing complete absence of weeds.

TABLE 12.—*Stand of tree seedlings and weeds on soil twice treated chemically*

Zinc sulphate treatment per square foot in—		Tree seedlings (1-0) per 4 square feet			Weeds per 4 square feet				
1922	1924	Thrifty	Unthrifty	Dead	Grass	Clover	Sorrel	Others	Total
Grams	*Grams*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
8	4	355	7	4	2	0	0	0	2
8	0	340	2	5	7	5	0	4	16
8	8	249	66	48	3	0	0	0	3
0	0	346	2	1	7	2	3	4	16

As was expected from the results of earlier tests the germination of pine seeds was increased slightly (about 5 per cent) in plots treated for the second time in 1924 with 4 grams of zinc sulphate per square foot, and except for some grasses the weeds were eliminated. The superior resistance of many grasses to zinc or acid poisoning has been noticed in several trials. Similarly at the Wind River nursery, at Stabler, Wash., the parallel-veined plants were found more resistant to sulphuric acid treatment than were the net-veined species, and Rabaté (*33*) found that spraying with sufficiently concentrated solutions of sulphuric acid killed all weeds except a few monocotyledonous plants such as grasses and cereals.

In 1924 the repetition of treatment using half the original amount of zinc was as effective on weeds as the repetition of the full amount. The latter treatment alone was injurious to the trees. While a few of the most thrifty individuals showed no apparent root injury, many of the seedlings, including the unthrifty ones, showed strong evidence of injury to the growing points, followed by decay of taproots. This observation points strongly to the conclusion that some of the insoluble zinc residue (probably zinc oxide or carbonate) in the soil had been rendered soluble either by the action of other compounds in the soil or by root action.

According to Freytag (*14*) the soil solution decomposes dilute zinc compounds as they filter through the soil and zinc is retained in the form of oxide. Baumann's (*3*) work indicates that the presence in the soil of such insoluble zinc salts, including the carbonate and sulphide, can not injure plants. But the work of Nobbe, Baessler, and Will (*30*) as reported by Brenchley (*4*) does not seem to agree with that of Baumann in that the insoluble zinc carbonate is included with the compounds that were found injurious. The dry weight of plants grown with small quantities of zinc compounds was less than for the controls, although no other sign of injury was noticed. Sorauer (*38, p. 753*) clearly expresses his view of the nature of the injury caused by zinc sulfate in soil in these words:

Zinc carbonate and zinc sulfate placed in the soil exercise an injurious effect. In themselves, to be sure, they are not injurious although they are soluble in pretty considerable amounts in water containing carbon dioxid, whereby the zinc sulfid is first changed to zinc carbonate. But their dangerous action lies in the transformation which the zinc undergoes in the form of vitriol with the potassium, calcium, and magnesium salts. In this these nutrient substances become soluble and may be wasted away. In poor sandy soils sterility may, indeed, be produced and the injuriousness of irrigation with waste water from the zinc smelters lies especially in this removal of the nutrient substances.

Storp (*39*) observes that the direct action of zinc compounds on plants is largely destroyed when these compounds are mixed in the soil, but suggests injury to soil due to the accumulation of insoluble zinc salts.

The observations of these men seem to be in full accord with the experience at Savenac nursery. Although the zinc residue in the soil may be harmless to plants in its insoluble form, it is nevertheless potentially injurious through its tendency to revert to soluble form. Although such a tendency is a menace to future crops, it may at the same time be the means of preventing permanent injury to the soil, by permitting the removal of injurious quantities of poison through leaching or absorption in the trees. Experiments have indicated that when second treatments are made two years after the original dose of zinc sulphate was applied, the quantity should be reduced to 4 grams per square foot.

Subsequent treatments have not yet been tested. It is hoped that by the time such treatments are needed the natural loss of zinc from the soil will permit of fresh doses in sufficient quantity to be effective on weeds without injuring the trees. Inspection of growing root tips of the trees on treated soil should be made each year in order to detect possible injury to crops. If at any time an appreciable amount of such injury is found it should be considered evidence of soil deterioration from accumulated zinc and the land should be treated with lime and humus or given a rest. The safest policy undoubtedly will be to avoid serious injury to the soil as a result of chemical treatments, but it is reassuring to note that Sorauer (*38, p. 753*) definitely stated the possibility of restoring fertility in these words:

> A soil ruined by zinc sulfate can be improved by the addition of substances which render soluble zinc salts insoluble.

He recommended the use of humus in the form of moor soil or stable manure and under all conditions some form of lime. Although it is possible that zinc treatment for weed control can not be continued indefinitely over the same areas with impunity, future tests of this treatment should aim at balancing the income and outgo of zinc in the soil, avoiding overdosage and accumulation.

USE OF ZINC SULPHATE ON TRANSPLANT BEDS

Although chemical control of weeds in seed beds had been very successful at Savenac nursery, following its adoption as an administrative measure in 1921, no attempt was made to test such control in transplant beds until four years later.

Chemical methods of weeding were not expected to be so efficient for transplants as for seedlings for several reasons. Transplants suffer less in competition with weeds because they are older and larger than most seedlings and because they compete less with each other. Standing in rows, transplants permit the removal of many weeds by cultivation, a process which seems to interfere with the toxic action of the chemical. Also, the open-ditch method of irrigating transplants may cause a greater leaching of the soil solution than the sprinkling method of irrigating seed beds. Nevertheless, some simple tests of zinc sulphate for transplant beds were made.

The last week in April, 1925, five plots were transplanted with 4-year-old Engelmann spruce seedlings and two plots with 1-year-old western white pine seedlings, each plot covering 176 square feet. A week later the spruce plots were treated with 8 grams of dry zinc sulphate per square foot and the white pines were given 12 grams. It was thought that this heavier treatment that had caused injury in seedbeds might not be injurious to transplants because of the larger amount of water passing through the soil. All of the beds were irrigated in the usual way, but not any of them were cultivated or weeded by hand until August.

Late in July, observation of the weed growth on treated soil as compared with that on adjacent untreated soil indicated that clover, sorrel, and cudweed had been almost eliminated, but that many large plants of lamb's-quarters remained. None of the weeds were counted and no significant difference in weed growth between the heavy (12-gram) and normal (8-gram) applications of zinc sulphate was apparent. The profusion of weed growth on untreated soil in contrast with the cleaner treated beds is shown in Plate 5. The lamb's-quarters in the treated bed are conspicuous because of their size rather than their number.

The trees surviving in certain beds four months after transplanting were counted. The survival of Engelmann spruce on treated soil was 81 per cent as compared with 89 per cent on untreated soil. The survival of western white pine was 77 per cent under heavy chemical treatment, 85 per cent under normal treatment, and 88 per cent without any treatment. The lower survival under treatment is attributed to action of the soil solution on roots, because no effect of the chemical on buds or foliage was noticeable. Probably the stumps of roots resulting from pruning at the time of transplanting did not directly increase the absorption of zinc. However, the shock from root pruning and transplanting may have weakened the seedlings sufficiently to increase their susceptibility to chemical injury, especially as the operation left them without their former absorbing rootlets in the deper layers of soil where the concentration of zinc probably was less than it was near the surface.

The treated beds of transplants were all weeded by hand in August, but the size of many of the weeds prevented the removal of all the roots. Weeds arising from root sprouts in 1926 were numerous in the treated as well as in the untreated plots. Although during the second year the trees were probably in a better condition to withstand further chemical treatment, it was not applied because it could not be expected to cope with weeds arising from roots. Summer fallowing between crops has since been found to be a fairly satisfactory way of dealing with the weed problem in transplant fields during the second growing season. As this has made the cost of hand weeding about equal to that of chemical weeding, there seems to be small need for any further trials of chemical methods of weed control for transplant beds.

LARGE-SCALE APPLICATION OF THE METHOD IN NURSERY PRACTICE

Chemical treatment was first adopted as a part of the practice at Savenac nursery in the fall of 1921 and has been used every year since then. The zinc sulphate is dissolved in water in a large wooden tank and is applied to the seed beds from ordinary sprinkling cans.

(Pl. 6.) The first year it was tried the treatment was found to be cheaper than hand weeding, but nevertheless fell short of expectations. Weeds were reduced in number, but not eliminated as they had been in the experiments. In large-scale treatments several possible causes of error were recognized and the precautions taken to reduce them in subsequent work have led to gratifying increases in effectiveness of the method.

DIFFICULTIES ENCOUNTERED

Among the more or less obvious causes of loss of the desired effect were the following five:

(1) When not thoroughly dissolved, zinc sulphate in various degrees of suspension following periodic stirring in the tank can not be evenly distributed on the beds, thus resulting in insufficient salt in certain spots to kill weed seeds and enough in other spots to harm the growth of trees. Similar results may be due to irregular distribution of salt from other causes such as careless sprinkling methods.

(2) Too little zinc sulphate may reach the seed-bed soil because of loss by run-off of the solution in paths or because of short weights due to the natural hygroscopicity of the salt. Accurate weights are dependent upon protection of the material from dampness. More about the run-off problem is given later.

(3) The method does not eliminate weeds which have sprouted from seeds previous to treatment nor those which may sprout at any time from broken roots in the soil. The work of Gericke (*15*) indicates that selective absorption by corky root tissue and precipitation of the injurious salt may account for the immunity of older plants from injury. Obviously the soil should be cleared of advance weed growth and broken roots by cultivation or handwork previous to treatment.

(4) Weed seeds from a distance may reach the soil through fertilizer or mulch material and some of these may prove to be highly resistant to, if not immune from injury by the treatment. Many wheat seedlings occured on treated soil following the use of wheat straw for mulch.[13]

(5) The chemical effect of fertilizers or the absorptive action of humus may reduce the effect of zinc sulphate on weeds. Soil containing a large amount of organic matter would undoubtedly require heavier doses of zinc sulphate in order to attain equal effect on weeds because of the retentive capacity of such soil for the soil solution. At the other extreme, sandy soil with its usual very low retentive capacity likewise probably requires heavy doses in order to prevent loss of effect. The formula worked out for weed control on the nursery soil was found ineffective on pure sand used in greenhouse tests at Savenac nursery in 1923. These observations agree with those of Baumann (*3*). He passed zinc solutions through various soils and tested the filtrate for zinc. Much was recovered from the sand, but none from the humus soil. In power to absorb zinc he rates humus first, clay and limerock soils next, and sand last.

Further experimentation was needed to determine the extent of the difficulty due to freshly fertilized soil. Following fertilization,

[13] Javillier (*22*) states that although wheat is clearly susceptible to zinc poisoning, it can benefit from small quantities of zinc compound.

sowing, and chemical treatment of plots in the fall of 1922, volunteer weed growth was observed in 1923. On unfertilized soil the treatment reduced the number of weeds by 89 per cent, whereas, on soil fertilized with 1 pound of dried blood and ground bone per 48 square feet, the reduction was 71 per cent, and on soil fertilized with 30 pounds of sheep manure per 48 square feet, the reduction was 72 per cent. Thus on fertilized soil the efficiency of chemical treatment was reduced by 17 or 18 per cent. This points strongly to the necessity for using a slightly heavier application of zinc sulphate. Otherwise hand pulling of those weeds escaping death from zinc would be essential because of the relatively more luxuriant growth of weeds which are not eliminated from fertilized soil.

According to Connor (*7*) lime may act upon injurious compounds in the soil in three ways. It neutralizes soil acidity; it precipitates most injurious soluble salts which are found in acid soils; and it antagonizes or opposes the action of excessive soluble salts which may not be precipitated. Among other metals Connor mentions zinc as one which is harmful in a soluble form but is rendered less soluble and less injurious by lime. This is in agreement with the results of True and Gies (*40*) who found that the growth of *Lupinus albus* seedlings suspended with their roots in zinc sulphate solution was retarded, but that when calcium sulphate was present, growth was more than twice as rapid as in the controls. In this case calcium reduced the toxic action of zinc to about one-sixteenth.

At Savenac nursery in 1925 two plots of 12 square feet each treated with hydrated lime, $Ca(OH)_2$, at the rate of 36 ounces per bed of 48 square feet, and the usual zinc sulphate application, produced 12 weeds as against one weed on similar plots receiving zinc sulphate but no lime. In another test, employing the same lime treatment accompanied by a 25 per cent increase in zinc sulphate, three weeds appeared on the fertilized soil and none on the unfertilized. The trees were apparently uninjured. These results are in line with the tests of other fertilizers, indicating the need for heavier doses of zinc, and they conform to Connor's findings concerning lime. The antagonistic action of fertilizers makes it seem desirable that they be mixed as deeply as possible in soil which is to be chemically treated, because the principal action of the weed poison is on or near the surface, whereas the tree seedlings can benefit from soil nutrients drawn from deep in the root zone.

The prevention of loss of zinc sulphate by run-off in the paths is connected with the concentration of the solution used. In the determination of the best amount, or dry weight, of salt to use per unit of area, an obviously safe quantity of water, 1 liter per square foot, was used in the first experiments. This amounted to about 12 gallons of liquid for each seed bed of 48 square feet and was found to be more than the soil could absorb at once. All areas were gone over twice in order to prevent loss from run-off. The additional expense of so doing was eliminated in later work after experiments had shown that such dilute solutions were not necessary. In the tests the original quart of water was halved, quartered, and omitted entirely on certain plots, the amount of salt being kept constant at 8 grams per square foot. Both western yellow and western white pine seeds were sown and their germinations, losses, and survival were closely observed. Developments were much the same in all plots, but survival was slightly lower in those plots that received dry salt, probably because of the lumps of chemical which prevented as uniform distribution as is possible when the salt is dissolved in water before being applied. Root examinations with a hand lens failed to reveal any abnormalities traceable to the chemical treatment. The elimination of weeds by the chemical in these plots was perfect, not a single weed being found during the season on treated soil. Plate 7 shows how the plots appeared. The primary purpose of this experiment, however, was fulfilled by the assurance that the usual quantity of zinc sulphate (384 grams or about 13½ ounces) may be distributed as satisfactorily over 48 square feet of soil surface by 3 as by 12 gallons of water.

FINANCIAL SAVING

The nursery manager reports that chemical methods have materially reduced the annual costs of weeding seed beds.[14] By hand methods the cost during two years for raising 2–0 planting stock is $1.40 per bed of 48 square feet, of which 40 per cent (or 56 cents) is the cost of weeding. Under the zinc sulphate method, similar 2-year costs are $1.02 per bed, of which 17.6 per cent (or 18 cents) is the cost of weeding. This weeding charge, of 17.6 per cent of production costs, consists of 7.8 per cent (or 8 cents) for the chemical, 3.9 per cent (or 4 cents) for the labor of applying it, and 5.9 per cent (or 6 cents) for subsequent hand weeding. Thus the use of zinc sulphate reduces the cost of producing 2–0 seedlings from $1.40 to $1.02 per bed, a saving of 38 cents. However, the usefulness of this chemical method can not be adequately stated in dollars and cents because the value of avoiding extensive injury to tree seedlings from hand-weeding methods has not been appraised.

LIMITED APPLICABILITY

Weed control in coniferous nurseries by the use of zinc sulphate is possible because of the especially high resistance of conifers, such as pine and spruce, to injury by small quantities of zinc. The common angiosperms, to which group almost all agricultural plants and weeds belong, do not possess this specific tolerance for zinc. Hence the method described here can find no application in general agricultural practice. Nor is it adapted for use in destroying weeds along railroad rights-of-way, in lumber yards, in driveways, or for similar problems because its specific effect has no value there. Wherever soil injuries are not important stronger doses of other common herbicides such as sodium arsenite are to be preferred. Even for coniferous seed beds zinc treatment can not be recommended for universal and unrestricted use, on account of the necessity for preserving soil productivity. Chemicals are needed only where the cost of hand weeding is excessive. They should not be used without preliminary small-scale tests in varied quantities and should be repeated only after the effects of the first dose have been determined.

[14] Weeding costs in terms of each thousand trees produced are omitted here for the reason already given in footnote 3.

Constant vigilance is necessary in order to avoid injury to crops and soil, or at least to prevent the repetition of any unintentional injury.

SUMMARY

The three most troublesome weeds at Savenac nursery are species of sorrel, timothy, and clover, introduced principally through irrigation water, manure, mulch, and wind. Chemical treatment of the soil to rid the nursery of these weeds has been thoroughly tested in beds of white and yellow pine, which constitute 85 per cent of the annual output of about 3,000,000 trees at the nursery.

The soil at Savenac has good physical properties, a high percentage of granular structure, and highly oxidized soil minerals. Organic matter is present in fair quantity, but not much of it is well decomposed. Lime in the form of calcium carbonate or calcium phosphate is absent. Potash feldspars, potash micas, and lime-soda feldspars are found. The soil tends to have an acid reaction, the irrigation water being slightly acid.

In 1915 various quantities of sulphuric acid applied to plots of soil in the nursery to arrest damping-off fungi were observed to reduce weed growth. In 1916 preliminary tests of chemical weeding were started, in 1918 intensive study of the subject was taken up, and in 1921 a chemical method based on the tolerance of conifers for zinc was put into general use to control the growth of weeds.

The application of the Savenac treatment is simple. It consists in applying 8 grams of zinc sulphate, $ZnSO_4.7H_2O$, known commercially as zinc vitriol or white vitriol, dissolved in 250 cubic centimeters of water, to every square foot of seed-bed area immediately after sowing the seed. This amounts to 1⅛ ounces of zinc sulphate per quart of water applied to every 4 square feet of seed bed. A new application of the zinc salt is needed for each successive crop of trees. The second dose should be only half the quantity of zinc originally applied, and the proper amount for the third dose can only be determined after close examination of the results of the first two doses, or, better still, by actual tests of the effect of applying different amounts of zinc on sample areas.

In the practical use of this treatment it is essential that care be exercised to obtain an even distribution of the chemical. The experiments indicate that if, through any cause, as much as 10 instead of 8 grams be applied to the square foot of Savenac soil, about 7 per cent of the growing root tips of the trees may be injured and that this injury will steadily increase with the overdosage. This observation does not apply equally to soils of different water-holding capacity, and heavier doses may be needed on sandy soils and those rich in humus. At Savenac nursery organic fertilizers reduced the efficiency of the treatment about one-fifth.

Results from year to year have varied a little, but each extensive trial has prevented the growth of at least four weeds out of every five in the seed beds for two seasons following the application. The treatment does not kill advance growth of weeds which may happen to be in the beds, nor pieces of roots or underground stems (runners) left from hand pulling, but it does prevent the germination of most of the weed seeds. They appear to be killed just after breaking their

seed coats in an attempt to germinate. The treatment seems especially efficacious with clover seeds and very effective with sorrel and timothy; most of the native weed seeds are readily overcome. In general the grasses have been observed to be least affected, and wheat seeds appear to be immune from injury, or nearly so.

The value of avoiding the injury to trees incident to hand weeding has not been appraised; but, at least, the use of chemical methods of weeding at the Savenac nursery has effected an annual saving of 38 cents in the cost of weeding each bed of 48 square feet.

The zinc-sulphate treatment for seed beds appears to have a tendency to stimulate the germination of pine seeds not only by reducing the time necessary to complete the germination of all viable seeds but also by increasing the total number of individuals that sprout. This tendency is probably due to the control of parasites or other indirect action, rather than to any direct stimulation of the seeds. Careful comparisons of the behavior of stock from treated and untreated seed-bed soil have been made during the various steps in nursery culture and later for the first three years after field planting, or until the trees were 6 years old. The treatment has been found in no way detrimental to the subsequent development, survival, and growth of western white or western yellow pine planting stock. The germination of Engelmann spruce seed is not injured by this treatment, but that of western red cedar seems to be reduced, probably because of the thin seed coats.

In transplant fields only one test of chemical treatment has been made. Most of the weed growth was prevented, but the trees were slightly injured.

The use of field peas as a green fertilizer crop on treated soil is possible because after a crop of tree seedlings has been grown and the soil is again plowed not enough soluble zinc is left to interfere with the germination of peas. The zinc residue in the soil tends to benefit the peas by increasing the number of nitrogen nodules on their roots. The effect of loss of zinc from treated ground is also noticeable even where the soil has been disturbed, as in lifting trees for shipment. Weeds have been observed to seed in freely on such areas.

Two forms of danger to the soil are recognized as a result of repeated applications of zinc sulphate. These are the development of soil acidity and the accumulation of zinc in quantities sufficient to injure the trees. Such danger exists in spite of the loss of zinc from the soil by leaching and by absorption in the trees.

The untreated soil at Savenac nursery is naturally acid, and sulphur in various forms tends to increase acidity. Zinc sulphate is expected to increase acidity because it is a salt of a weak base and a strong acid. So far the areas that have been given the chemical weed treatment have not been noticeably more acid than adjacent untreated areas; but lime has already been used throughout the nursery to check the general tendency toward acid reaction on untreated soil, and in the future it is possible that more lime will be needed not only to neutralize acid but also to inhibit the toxic action of zinc on areas treated with zinc sulphate.

Although tests made by the Forest Products Laboratory at Madison, Wis., failed to reveal any trace of soluble zinc in treated soil two years after the application of zinc sulphate, small quantities of insoluble zinc were found. A second crop of trees on this soil was injured by a repetition of the original zinc-sulphate treatment in full amount but was unharmed by an application of half the original dose. Apparently the deposit of insoluble zinc, representing a part of the original amount added to the soil, had again become soluble and existed in the soil as a menace to the crops.

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QUAKING ASPEN

A STUDY IN APPLIED FOREST PATHOLOGY

BY

E. P. MEINECKE
Principal Pathologist, Office of Forest Pathology
Bureau of Plant Industry

UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D. C.

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QUAKING ASPEN: A STUDY IN APPLIED FOREST PATHOLOGY

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CONTENTS

INTRODUCTION

In the management of quaking aspen (*Populus tremuloides* Michaux), as well as of any other species of forest tree, two factors are of decisive influence, namely, the possibility of securing the maximum volume production in sustained yield on a given area and on the other hand that of reducing to a minimum the loss from decay and other injurious factors. Maximum volume production must mean the maximum yield of sound high-grade lumber obtainable from a given species grown under given conditions. The definition of high-grade lumber will depend in each case on the use to which the lumber is to be put.

Aspen in Utah, largely owned by the Government (*1*),[1] has in the past found a limited market as mine props and a local use as posts, poles, and fuel. To-day coniferous props have more and more taken its place in the coal mines of Utah. Unless new uses can be found, aspen will have to be considered as a weed tree, and as such will rank with the lowest of the inferior species. Its value as browse does not lie within the scope of this study.

[1] Reference is made by italic numbers in parentheses to "Literature cited," p. 33. The data offered in the present study are based on investigations conducted for the intermountain national forest district and have been used in F. S. Baker's bulletin (*1*).

The utilization of aspen for pulp in other parts of North America has suggested a similar use of the species in the intermountain national forest district. The present investigation is, therefore, based entirely on the assumption that aspen in Utah may in the future find a ready market for use as pulp and perhaps also as excelsior and matchwood. Obviously, the growing of aspen can be profitable only if the loss from decay and other factors does not cut too heavily into the expected yield.

That aspen in the storage pile is highly susceptible to the attacks of saprophytic fungi is well known. The losses from this source are extremely heavy. In this study, however, the cull factor will be considered only as it affects standing timber.

In wood used for pulp where the raw material is mechanically broken up into minute particles, the cull factor must play a rôle entirely different from that in saw timber. Nothing definite is known as to the proper procedure for estimating the amount of cull from decay in quaking aspen. Under present commercial practices, culling for rot is rather lax on account of the heavy demand and the growing scarcity of pulpwood. The manufacturer can not afford to pay top prices. He must use inferior grades and naturally expects a certain amount of rot.[2]

That decay very materially affects the weight is shown by Kress and Bearce (*9*). Studies by the Forest Products Laboratory, Madison, Wis., show that there is an appalling loss to the paper industry from decay. Correct determination of these losses can not be arrived at by the cord or volume measurement of pulpwood, which latter, while undergoing decay, suffers no change in volume, but does decrease decidedly in weight. Scalers attempt to estimate rot in wood, but this estimate is arbitrary and often incorrect. Examination of a number of shipments of infected spruce shipped to the Forest Products Laboratory for pulping trials showed a maximum variation in comparison with sound wood of 5 pounds per cubic foot of bone-dry wood. This represents a loss of 19 per cent on actual wood substance.

No information whatever is available to serve as a basis for the use of loss in weight as a criterion for the pulping value of decayed aspen wood. It is known that *Fomes igniarius*, by far the most common and most destructive of the fungi attacking quaking aspen, first breaks down the lignins in the cell walls, leaving fragments of cellulose which in their turn are consumed as the decay progresses. Schmitz (*13*) has demonstrated the presence of cellulase and hemicellulase in the mycelium of *F. igniarius*. Nothing definite is known as to the rate at which the reduction of the cellulose content proceeds. But it seems fair to assume that in the latest stages of decay, which are characterized by pronounced softness and loss in weight, such changes have taken place that the wood is no longer useful for pulp. In the lighter stages of decay, not accompanied by pronounced softness and loss in weight, the cellulose content may be considered as not seriously impaired, though the lignins may already be partly consumed. In the course of the study in the field the decays were

[2] Thanks are due Otto Kress, formerly in charge of the section of pulp and paper, Forest Products Laboratory, Madison, Wis., and to J. D. Rue, in charge of the section of pulp and paper, Forest Products Laboratory, for the facts and considerations given in this section of the bulletin.

arbitrarily classified according to hardness and consistency, due consideration being given to apparent loss in weight.

OBJECTS OF THE STUDY

The objects of the present study can be summarized as follows:

1. Determination of present cull per cent per age class in standing aspen intended to be utilized for pulp, the cull being expressed in volume and in degree of hardness. Since even decayed aspen wood may be expected to make pulp as long as the decay has not progressed too far, only those cases of decay are included in the cull in which the wood has become soft and cheesy and has lost materially in weight. Earlier stages of decay, not accompanied by decided softening and loss in weight, are considered as negligible and are therefore not culled. Causes for cull other than decay are rated according to whether they are likely to interfere with the pulping process. Lightning scars are negligible. Frost cracks and shakes, which are so prolific a cause for cull in saw timber, have no direct bearing on the quality of the pulp, nor do they interfere with the pulping process. In fire scars the immediate loss is one of actual destruction of wood mass. Insect borings cause a direct loss in weight, though this is rarely of much importance. The wood separating the individual galleries is not depreciated for pulp purposes as long as it is not decayed. More difficulty was encountered in determining what should constitute cull for canker. Barking is an important item in the pulping process and requires for perfect functioning more or less even round sticks. Cankers interfere more or less with this requirement. No hard and fast rule can be set for culling on account of canker. Each case has to be considered individually on its own merits, on the basis of a probable interference with the mechanical handling of the stick.

2. Determination of the age beyond which decay in aspen becomes economically important. Very young trees are little subject to culling factors or are killed before they become established as permanent members of the forest community. With increasing age they are subject to cumulative risk (*11, p. 9*) from a number of injurious factors, among which decay is one of the most important. Fungi, like all other plants, demand for their proper development a minimum mass of substratum from which to draw their subsistence, some, such as molds, being content with very small quantities; others, like the common heartwood-destroying fungi, being able to live and fully develop only in larger masses of wood in which they find proper living conditions and room for expansion. The older trees, then, present conditions more and more favorable for the growth of the group of fungi causing cull in living aspen. Studies in white fir (*Abies concolor*) and incense cedar (*Libocedrus decurrens*) have shown that, although both species are susceptible to infections by heartwood-destroying fungi soon after heartwood begins to be formed, decay does not become economically serious until the trees reach a greater age. The determination of the age class from which onward the loss from decay tends to reduce materially the gain from increment in the virgin forest furnishes a basis for the pathological felling age. The determination of the age class from which onward the loss from decay tends to reduce materially the gain from incre-

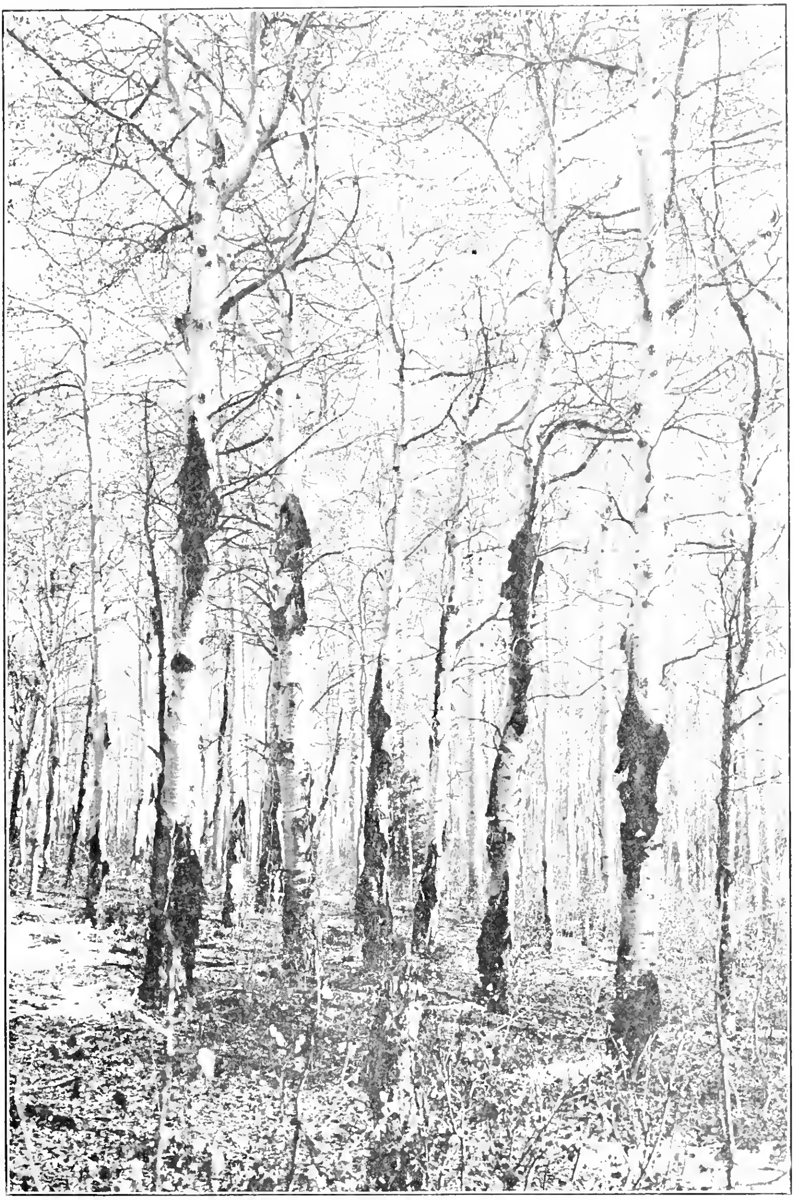
ment in the managed forest from which all undesirable individuals have been eliminated permits the establishment of a pathological rotation, indicating the period beyond which it will be unsafe to leave aspen uncut on account of the loss to be expected from decay.

PATHOLOGY OF ASPEN

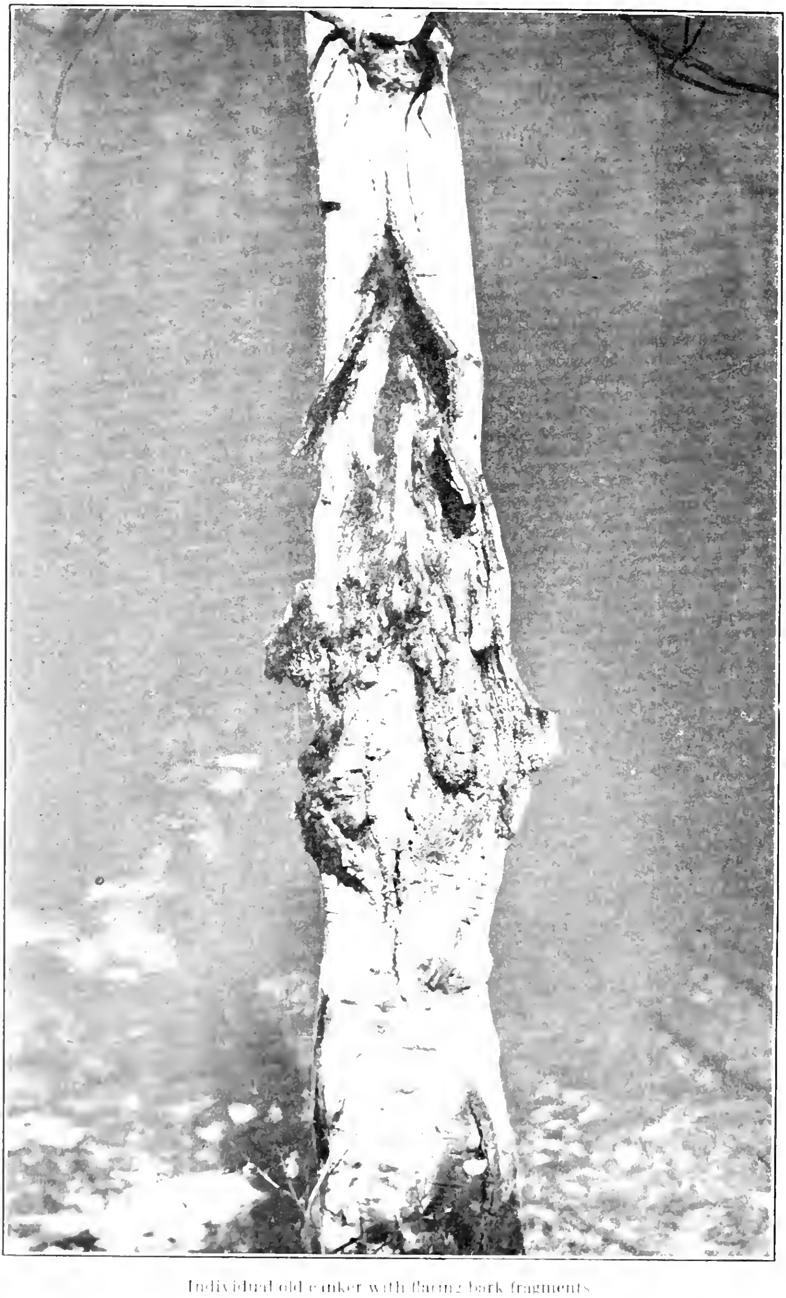
Quaking aspen is highly susceptible to disease (*5*). The increment of wood added is more or less severely affected by a number of leaf diseases. *Sclerotium bifrons*, according to Hartley and Hahn (*5*), is common and of some importance in Colorado and sometimes is responsible for the killing of half of the foliage of considerable forest areas. In Utah the fungus seems to be negligible so far, but will bear watching. A leaf rust, *Melampsora albertensis* Arth., is common but does little damage. *Uncinula salicis* also is common but of minor importance. A leaf spot, closely related to *Marssonia populi*, but differing from it somewhat in spore characters, is exceedingly common in the region studied and can not be without influence on increment.

The bark of quaking aspen in Utah is subject to a number of troubles, of which canker is by far the most frequent and serious. (Pl. 1.) The cause of this disease is still unknown. Several fungi have been observed (*5, p. 145; 8, 10, 12*) in connection with cankers in other parts of the country. None of these appears to be involved in the Utah aspen canker. It seems, however, to be closely related to, and perhaps identical with, a canker type of unknown origin described by Long (*10, p. 332*) as occurring on older trees in Arizona and New Mexico. Little of a definite nature can be said even of the development of the canker. Not all infections, if infection there is, are able to survive. Often the canker growth stops, and the affected area heals over. Whatever the primary cause, the canker is characterized by a local killing of the bark which, especially in thinner stems, may lead to complete girdling and killing. In other cases a callus around the killed area is formed which may in its turn be attacked and killed back. Typical older cankers present a central dead area surrounded by a series of calluses from which the old rigid bark stands out in ragged fragments. (Pl. 2.) Often the cankers grow to very large size and disturb the symmetry of the bole locally to such an extent as to render it unfit for any use for which round timbers are required. Canker is beyond doubt a serious menace to aspen growth. It is firmly established in Utah and very common. The fact that it occurs principally in isolated foci within which almost every tree is affected, while adjoining areas are free from the disease, suggests an infectious origin and therewith the possibility of local control by systematic elimination of cankered trees or cankered branches and limbs.

The wood of standing quaking aspen is attacked by several fungi, foremost of which is *Fomes igniarius* or false-tinder fungus. The fungus causes a typical white rot of the heartwood, but later the mycelium attacks the sapwood also and may reach the cambium. At first brownish streaks appear in the still firm wood. Later the wood becomes white, dry, and very soft, so that it cuts more smoothly than soft pencil wood—much like dry cheese, but for the stickiness of the latter. In this stage it resembles closely balsa wood (*Ochroma lago-*



Aspen stand in central Rocky Mountains heavily affected by canker



Individual old canker with flaring bark fragments *pus*). The transition from the first stages of decay to the cheesy stage seems to take place rather quickly, at least under conditions favorable to the growth of the fungus.

Fomes igniarius follows aspen throughout its range, and everywhere heavy loss goes with it. Hartig (*4, p. 114*) was the first to call attention to its extraordinarily destructive properties and to give a detailed description of its morphology and the peculiar mode in which it attacks the wood of its hosts. Weigle and Frothingham (*15*) state that in Maine and New Brunswick the immense stands of aspen which followed the fires of 1825 are so rapidly deteriorating from white rot (*F. igniarius*) that many of these 80 to 90 year old stands must now be culled by from 5 to 20 per cent. These writers give detailed examples of the heavy losses from decay encountered in individual logging operations. According to Cameron (*3*), at least one-half of the aspen around Lesser Slave Lake in Canada is useless, owing to the attacks of *F. igniarius*. Von Schrenk and Spaulding (*14*) state that in the New England States, in Colorado, and in New Mexico it is almost impossible to find healthy stands of aspen that have attained any age, because of the extreme destruction brought about by *F. igniarius*.

Second in importance is *Fomes applanatus*, though not nearly so common as the former. It causes in aspen a light-colored rot of the heartwood, sometimes extending into the sapwood. *F. applanatus* is generally confined to the butt of the tree and therefore rarely becomes economically important, though it may be locally destructive. White (*16*), in a detailed study, considers the fungus as a parasite which generally enters the host through a wound on a root near the collar or on the trunk. It works inward to the heartwood and thence upward, involving the lower sapwood. Though the decay is largely confined to the lowermost few feet of the trunk, it may occasionally extend upward some 12 or 15 feet. In early stages the wood shows a characteristic mottled appearance. At this stage the wood is still hard and heavy. The final stage of decay is indicated by uniform white color of the wood. By this time the wood has become very soft and light in weight and rather spongy. Heald (*6*) states that the fungus enters the base of the trunk near the ground line and that, in specimens observed, the decay reaches a height of 10 feet. The wood becomes very brittle. He found no infected trees below the age of 30 years. Hedgcock (*7*) reports this fungus from the Manti National Forest near Ephraim, Utah—that is, from the locality where the present study has been conducted—as causing a serious root rot reaching into the butt of the tree; he attributes to it considerable loss on moist slopes. The writer also has observed the fungus in the same and other localities in Utah. The fungus does not seem to fruit freely on the area under investigation. In the course of the study only two cases of decay from *F. applanatus* were found that were connected with sporophores, both of these being in the stump and causing only negligible loss. The close analogy with the action of *F. igniarius* justifies the assumption that here also pronounced loss in firmness and weight in the uniformly white stage is accompanied by chemical changes which render much decayed wood unfit for pulping.

A very similar decay occurring on the area studied tallies with the familiar decay of *Fomes applanatus* except in two points. It seems to be confined to the heartwood, and in severer cases the affected wood degenerates into a very stringy, wet, and soggy mass, of a character so far not described for *F. applanatus*. White (*16, p. 158*) has found that purely secondary saprophytic bacteria and fungi practically always appear in the advanced stages of decay caused by *F. applanatus*. It is not impossible that the stringy and soggy consistency of what is here called "stringy butt rot" is due to a further disintegration by secondary fungi and bacteria. Like the decay of *F. applanatus*, it is typically a butt rot which, in all respects except the two mentioned, resembles *F. applanatus* decay so closely that one is inclined to attribute it to this fungus. Although the total absence of sporophores connected with this stringy butt rot made definite identification in the field impossible, the close similarity, coupled with the fact that *F. applanatus* is known to be not uncommon in the region under investigation, may justify a tentative listing of this stringy butt rot under *F. applanatus*. In general, the type of decay is akin to that of *F. igniarius*, so that for the practical purposes of this study pronounced loss in firmness and weight was made the criterion of cull for the stringy butt rot as well as for genuine *F. applanatus*. The stringy butt rot contributes only slightly to the total loss from decay, and the possible error hardly influences the final results.

A number of minor secondary decays are very common, never reaching an extent or degree of rot, however, which could have any bearing on the use of the affected wood for pulp. In the absence of sporophores, the determination of the causative fungi is impossible except through laboratory cultures, which at the time of the study was not feasible. These decays, while noted and measured, are considered unimportant and negligible for the purposes of this study. None of them is liable to influence the loss factor.

All in all, sporophores of wood-destroying fungi are relatively infrequent in this region.

PRINCIPLES AND METHODS OF INVESTIGATION

The immediate vicinity of the Great Basin Range Experiment Station, Utah, located at an elevation of 8,750 feet, in the Wasatch Range of the Rocky Mountains, was chosen by local members of the Forest Service as representing good average aspen for Site I. A comparison with Baker's data indicates that the area covered stands rather between Sites I and II. It goes without saying that the results presented in the following pages hold good only for the area surrounding the Great Basin Range Experiment Station and other areas comparable to it. But since it is not to be assumed that aspen on the poorest sites will be utilized or put under management for pulp wood, the general conclusions will be valid for all sites likely to be considered.

FIELD METHODS

The methods used in the field were much the same as those first used by the writer in the study of the pathology of white fir (*11*) and later by Boyce (*2*) for incense cedar. They were, however, adapted in the field to the altered conditions arising from difference in the species concerned, size of trees, and the special object of the study. Suitable smaller areas were selected on which every tree was cut. On other areas a certain selection of trees was made so as to secure as closely as possible a cross section through the stand, within certain age and diameter limits, the aim being to obtain data on all trees which could be regarded as truly representative of the merchantable stand as it actually exists, with regard to its utilization in the near future. For this reason the analysis of seedlings and saplings below 30 years of age and of all trees plainly outside of the limits of possible utilization—such as trees unusually misshapen and distorted or trees which obviously were dropping out of the permanent stand—was excluded.

In conformity with the object of the study, an effort was made to balance the different age classes as nearly as possible. Exact data were taken for each tree on diameter breast height, height, crown class, age at stump (1.0 foot), diameter inside bark at stump (1.0 foot), diameter inside bark at the upper end of the 8-foot logs to 2 inches diameter in the top, and, where this last was impossible, the diameter inside bark at 2 inches diameter was computed. Particular attention was paid to description and location of wounds of different types on the bole, sporophores, etc. The trees were bucked in 8-foot lengths, and careful diagrams were drawn of each cross section, giving in detail and with exact measurements the extent of decay and of internal wounds. The individual logs were split and the decay as well as wounds measured, described, and sketched in a longitudinal diagram. Wherever feasible, the point of entrance was determined through which decay had established itself in the tree.

Decay was accurately described and graded. Specimens of different grades of decay were collected, in order to permit checking of the field notes in the laboratory.

In the course of the study it was soon found that *Fomes igniarius* decay and a "stringy butt rot" (*F. applanatus?*) were the only factors causing, in the later stages, such loss in firmness and weight that cull, in the sense discussed above, ensued. Of these, *F. igniarius* is by far the more common and important. For the sake of completeness equally accurate data were taken with regard to incidental minor decays caused by a host of undetermined mycelia, all of which are classed as secondary. These secondary rots also enter through wounds but never penetrate deeply into the wood, generally being confined to the immediate vicinity of the wound or opening itself. They are without importance from the point of view of utilization for pulp.

COMPUTATIONS [3]

All volumes were figured in cubic feet inside bark. The bole was considered as a paraboloid, but the stump was figured as a cylinder with the diameter of the stump-cut at 1 foot, and the top as a cone above the highest diameter measurement. Limb and branch wood was not included. In accordance with data furnished by Doctor Kress, Forest Products Laboratory, the merchantable volume was figured from the stump to 2 inches (diameter inside bark) in the

[3] All questions of mensuration were first submitted to Donald Bruce, division of forestry, University of California, to whom thanks are due for the great interest he has taken in this phase of the study and for the valuable advice given.

top. Where it was not feasible to obtain the height to 2 inches (diameter inside bark) in the top by direct measurements, the volume to this point was computed by the following formula: $V = \frac{H}{3}\left(B - \frac{0.044}{D}\right)$ in which D = last (highest) diameter taken, N = volume of the frustum of a cone between the point where D is taken and the 2 inch (diameter inside bark) point, H = height between point where D is taken and the tip of the tree, and B = basal area of D. Volumes of logs were computed by the Smalian formula, average diameters at the ends of logs being used.

In general, forks and broken tops were disregarded, and the longest fork or the longest volunteer was taken as the leader.

PRINCIPLES OF CULLING

The actual volume of wood immediately affected by decay, canker, fire scars, etc., was first figured as "net loss." The "net cull" is the volume of the log or part of the log rendered unmerchantable by the net loss factors, including, for example, thin layers of sound sapwood which could not be utilized independently.

In those simple cases in which heavy decay runs throughout the entire wood of a log, as for instance in severe attacks by *Fomes igniarius*, the net cull represents the loss from a commercial point of view. But frequently there are complications, where, for instance, two streaks of decay or decay and a fire scar run so close together that it will not be possible to utilize the sound wood separating them. In such cases the net cull volumes from both causes plus the volume of sound wood rendered unusable is totaled as "gross cull." Gross cull, in the final analysis, is the total commercial loss, so that in the case of a log completely destroyed by *F. igniarius* the net cull volume equals the gross cull volume. In other words, the gross cull corresponds to cull deduction to be made from the total gross scale.

For the purpose of figuring the cull per cent of the stand, only gross cull volume, the grand total loss from all causes, is of interest. For the proper understanding of the rôle played by the various injurious factors themselves, fungi, fire, canker, etc., however, the net cull volumes must be used. The mere fact that two cull volumes happen to be placed so close to each other in the bole as to render the sound wood separating them commercially valueless can not justify a procedure in which this volume of wood is charged against either one of the culling agencies.

In order to express intelligibly the degree of decay as observed in the field, it was found advisable to adopt three grades. The first grade represents genuine rot in a solid mass, causing so pronounced a loss in firmness and weight that the wood has to be considered a total loss for pulping purposes. The second grade covers the same kind of rot, but it extends through the wood in isolated streaks instead of forming a solid mass. The third grade indicates advance rot (*11, p. 35*), referred to by more recent writers sometimes as "incipient decay," and includes lighter decays of various origin involving no appreciable loss in hardness and weight. Grade 1 causes net loss of the entire volume it occupies. In grade 2 the streaks of decay cause net loss of the streaks themselves but not of the rest of the wood, and allowance is made on that basis. Grade 3 is considered negligible for the purposes of this study. It must not be overlooked, however, that both streaks and advance rot represent but earlier stages in the development of the fungi concerned and that both will in due time develop into grades 1 and 2, respectively.

Where heavy rot extends throughout or through most of the heartwood of a log or bolt, that log or bolt is culled completely as net cull (in this case equaling gross cull). Since logs of small diameter are not much less expensive to handle than larger ones, while proportionately the loss from decay, etc., is greater, culling should logically be heavier on a sliding scale the smaller the diameter of the log. Lacking such a sliding scale it was found advisable to cull logs or bolts below 6 inches in diameter more heavily than the large sizes.

When the rot volume extending through a log did not occupy the entire heartwood, the volume of the rot column was generally figured by the Smalian formula, because the form of the rot column through a log usually is that of a frustum of a paraboloid. What little variation from the paraboloid form there may be in such cases can lead only to negligible error.

The great diversity in form of the cankers led to some difficulty in culling. All degrees and transition forms are encountered, from the initial small stages to large flaring, highly irregular deformations, which latter, at least, can not be without influence on the barking process. Scaling for canker was therefore largely governed by considerations of presumable difficulties which smaller and larger, relatively smooth, and very ragged cankers might cause in the barking machine. In addition old cankers, in which a succession of irregular calluses had brought about pronounced deformations of the bole or distortions of the wood fiber, were culled heavily, while lesser injuries were ignored, in accordance with the fact that injuries other than rot are largely overlooked by the pulp industry. So far as known, canker, where present at all in the aspen regions now under exploitation for pulp, causes so little damage that no attention seems to be paid to it. In Utah, however, canker is so common and destructive a factor that it could not be left out of the equation in figuring the chances of a prospective pulp-wood enterprise. Whether the quality of the wood with regard to utilization for pulp is actually impaired remains unknown. Canker does not destroy wood already formed, but the wood lying underneath the canker is often stained orange red or dull orange and seems to be more brittle than normal wood.

The loss in local increment caused by the killing of the cambium is largely compensated by the excess growth in the calluses. Actual wood volume in a cankered area is apparently not much smaller than in the normal stem. The wood mass is simply differently arranged in space, and the area of the roughly triangular cross section through a canker may be the same as the area of a corresponding sound cross section. The more pronounced the deviation from the circle the greater will be the difficulties in working up the wood and the heavier should be the culling.

COMPILATION AND TABULATION

The compilation of the data followed in the main the principles laid down in former studies (*11, pp. 36–46*). The basic material consisted of 240 trees, ranging from 30 to 168 years in age and from 2.3 to 18.1 inches, d. b. h. The representation from 41 to 120 years is fairly even. The 30–40 and the 121–130-year age classes have 15 and 14 trees respectively. Above 130 years the numerical bases become weaker, and the data can only be used with proper caution. The total merchantable volume amounts to 1,237.3 cubic feet.

The individual trees, arranged by their ages, are first listed on the " basic sheet," on which all fundamental measurements and data are entered from the field notes. The bare facts of the basic sheet are then analyzed and condensed. Obviously immaterial notes and figures are eliminated, and all pertinent facts are given in the simplest mode of expression consistent with accuracy and clearness. Those data which do not speak for themselves when expressed in figures are reduced to easily comparable symbols. One, two, or three crosses (x, xx, xxx) denote the relative degree of each factor. Three crosses are equivalent to the highest degree and one to the lowest, with two crosses as medium. The system has the advantage of simplicity, and readily adapts itself to different purposes where an understanding of general relationships rather than the presentation of definite facts is sought.

The relative importance of decay itself, when expressed in cubic feet, becomes apparent only through constant and cumbersome reference to the volume of the tree affected. The application of the cross system reduces the mass of figures to directly comparable values. The decay is rated in crosses on the following arbitrary scale:

X=0–10 per cent of the merchantable volume of the tree.
XX=11–30 per cent of the merchantable volume of the tree.
XXX=31–100 per cent of the merchantable volume of the tree.

On this basis x is a light grade, xx is more serious, xxx is very heavy. A cross in parentheses (x) represents a case with hardly even the value of x, so that (x) and x may be entirely disregarded from a commercial point of view, but not from the standpoint of the forester, since light decay may in time develop into serious damage.

In former similar studies it appeared that a relation exists between decay and rate of tree growth, that the slower the growth of the tree in the aggregate the greater the loss from decay. Rate of growth was expressed by the relation of the actual to the average volume of trees of the same age. In the present study the volumes, including stumps and tops, were averaged for each 10-year age class, after the age for the number of trees in each age class had been averaged, and a curve was constructed from the data obtained. In comparing the volume of the individual trees with the volume as given by the curve, seven groups were established, of which the middle one, coinciding with the values of the curve, is called standard. One, two, or three crosses indicate the degree to which the volumes of the individual trees fall below or rise above the standard, and on this basis the following arbitrary rating is adopted:

0–10 per cent deviation above and below=standard.
11–25 per cent deviation above and below=x.
26–50 per cent deviation above and below=xx.
51–100 per cent deviation above and below=xxx.

The percentages of deviation refer to the standard taken as 100. The terms suppression and dominance as used in former work are at best vague and could serve only in the absence of a better terminology. They are supplanted here by "above standard," "standard," "below standard." "Dominance" and "suppression" are terms denoting a relation of the tree to site, and for this the height index is considered to be a better indicator than volume over age. In the present case the emphasis is not on site but on the relation of wood-destroying fungi to individual trees of different physiological value. The tree itself represents the site for the fungus living in it.

That decay in forest trees stands in close relation to wounds is a well-established fact. Though certain fungi attack the tree through the roots, the great majority effect their entrance through open wounds which expose the wood. The chances for infection increase with the number and size of the wounds and with the length of time the latter remain open. These factors which play so important a rôle in the pathology of the trees can not be illustrated by simple figures. In the analysis of the basic sheet each wound is given a rating which expresses with the help of the cross system as clearly as possible its bearing on infection and on the functional life of the tree. A large fire scar, which may take 100 years or more to heal over, is rated very high, while the very thin cleft of a frost crack offering only a small opening into the interior of the bole receives a low rating. Canker ranks partly as a cause of wounds, partly as a physiologically weakening factor. Cankers form more or less large openings which give fungi free access to the wood. The killing of large patches of bark interrupts locally the free flow of assimilates and often approaches the conditions of a partial girdling. The rating of canker is based on the number of cankers on the individual tree and the relation of the killed bark surface to the total bark surface of the tree.

From the basic sheet the analyzed data are now transferred to the main sheet, on which the individual trees are entered by their ages. The main sheet with its condensed data becomes the principal working basis for final analysis.

ANALYSIS OF DATA

An analysis of the main sheet with its symbolized values brings out strongly the fact that age is an important factor in the occurrence of decay.

The first case of decay, though negligible, occurs in a tree 35 years old. Weigle and Frothingham (*15, p. 19*) state that in Maine and New Hampshire the aspens are attacked only after about the twentieth year, while Von Schrenk and Spaulding (*14, p. 32*) report that aspen becomes infected after the trees are 20 to 25 years of age. The age of infection simply indicates that trees beyond that age are subject to infection but not necessarily to serious decay.

That trees may in rare cases be badly decayed, even at an early age, is shown by a 39-year-old individual. The tree was heavily wounded and much below standard in volume and is the only seriously affected one among the first 67 trees of the main sheet. To put it in other words, the trees of younger ages, comprising 28 per cent of all trees tabulated, are practically free from economically important decay. The next trees where rot appears are respectively 57 and 62 years of age, and both trees are apparently without open wounds and above standard. The first has been badly cankered for 38 years, or since it was 19 years old. But again these are exceptions. In the following 28 trees only one case of medium importance occurs. From the age of 78 years upward, cases of heavy decay become more frequent, mostly in trees very much below standard and heavily wounded. A marked increase seems to come in the second half of the nineties and is more pronounced from 101 years on. Though heavy decay is still found in trees both much below standard and heavily wounded, the cases of serious decay in which one of these factors may not be present become more and more frequent. The turn seems to take place from about 111 years on.

The analysis of individual trees arranged by their ages makes it appear that in the wild stand, as it exists to-day, with its many wounded and slow-growing trees, decay becomes a factor of loss from the eighties on and causes serious loss from 100 years on. From about 110 years upward the loss is heavy in trees that are much below standard, although only slightly wounded, or in badly wounded trees although much above standard. Above that age even thrifty trees are likely to be seriously decayed.

Another point that is strikingly brought out is the steady increase in new infections with age. From 57 years onward, the increase is very noticeable. The older and larger the tree, the greater is the cumulative risk (*11, p. 9*) of wounding and, consequently, the chance for infection.

CUMULATIVE RISK

The cumulative risk is illustrated in Figure 1, based on percentages of trees infected. A few of the latter have two or even three infections. For practical purposes they are considered as one. It is of little more than academic interest to know whether a certain volume of decay is due to a single or to several infections. The lines show the general trend of infections with age, expressed in percentages of infected trees for 10-year age classes. The solid line combines all infections. From low levels it rises abruptly and steeply until in the 121–130-year class 93 per cent of the trees show infection. For the characterization of the two broken lines decay ratings are used, decay being nothing but the result of infection. The lighter, negligible ratings, (x) and x, have been united in the dotted line, while the third line comprises the heavier ratings, xx and xxx. The percentages of light decay ascend rapidly to the 60-year age class and then show a steady downward trend, contrasting with the sustained ascending tendency of the line for heavy decay, which swings up rapidly and markedly in the 91–100-year age class, running almost parallel with the line for the combined infections.

The following deductions may be drawn with safety. The risk of infection as well as the probability that an infection will develop into heavy decay are functions of time. Infections with heavy decay are rare up to the last decade of the first century of the trees' life and then gain rapidly in frequency of occurrence. Light decays are preponderant up to 60–70 years, after which age class they decline in number. Evidently many of the lighter infections turn into heavy decay after that age. A certain number taking place later in life never reach the stage of heavy decay.

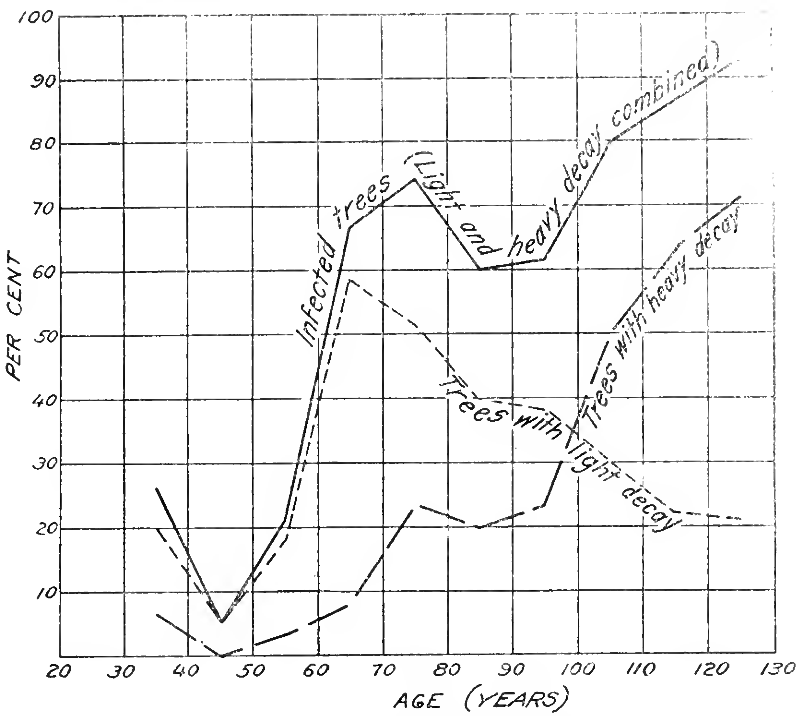


FIGURE 1.—Percentage of trees with infections, by age classes. The ratio of infected trees increases steadily with age. With time the infections develop into more and more serious decay

WOUNDS AND INFECTIONS

That most heartwood-destroying fungi are incapable of infecting a tree unless a wound offers an opening to the wood has been amply demonstrated. The term wound, therefore, applies here only to such lesions as expose the wood to infection. By far the greatest number of wounds in forest trees in general are scars caused by forest fires, by lightning, by insects, by logging, by wind breakage and bruising from falling trees and heavy limbs, and by frost cracks. In quaking aspen a specific factor, canker, is added to the list. Its peculiar rôle justifies a separate treatment of the subject, which is, therefore, not included in the general discussion of wounds.

Since infection depends on the chance of floating spores landing on exposed wood under conditions favorable for germination and final establishment, the bearing of wounds on ultimate infection is characterized by the relative surface of wood exposed, either in single large wounds or in a multitude of smaller ones, by the length of time the wound remains open before it is healed over, and by the character of the exposed wood as a suitable medium for the fungus involved.

The great majority of wounds in aspen remain open for many years. This is largely due to the fact that most of the wounds consist of fire scars or bruises, both of which destroy or kill such extended portions of bark surface that healing by callus can only be a very slow process. This condition increases the cumulative risk of infections through these types of wounds. The longer they remain open the greater the chances that they will finally become infected.

Less than one-fifth of the wounds examined were healed, and apparently these were lesions of little consequence. In nine cases it was possible to determine the years in which the wounds originated and in which they were finally grown over. The periods covered in the healing process are as follows: 7, 13, 21, 24, 25, 25, 30, 30, and 48 years. All wounds large enough to cause immediate loss (direct cull) were still open, though some of these dated back 100 and even 150 years. It is apparent that quaking aspen heals at least its larger wounds very slowly and that lesions remain open to infection for an unusual length of time.

An analysis of the type of wounds (Table 1) shows plainly that infections are commonest for those wounds which either present a large open-wound surface, like fire scars and bruises from falling trees, or form a spore trap, like ingrown stubs and broken tops with their rough surface of splintered wood.

TABLE 1.—*Wounds in relation to infection and cull (exclusive of canker)*

Type of wound	Wounds		Number of resulting cull cases			Direct cull caused by wounds	Net cull from rot	
	Total	Infected	x	xx	xxx		Total merchantable volume	Total gross cull
	Number	*Per cent*				*Cubic feet*	*Per cent*	*Per cent*
Open wounds:								
Fire scars	83	88.0	11	20	26	7.38	14.5	68.0
Bruises	55	32.7	4	1	2	.07	.34	1.6
Dead and broken tops	27	18.5			1		.30	1.4
Dead forks	3	0						
Ingrown stubs	10	60.0	2	1		.04	.10	.48
Frost cracks	12	16.6						
Lightning	2	0						
Miscellaneous	8	0						
Undetermined	10	20.0						
Total	210	50.5	17	22	29	7.49	15.2	71.5
Healed wounds:								
Fire	14	57.1	3				.02	.12
Bruises	8	12.5						
Miscellaneous and undetermined	23	34.7	2	1	1		.08	.39
Total	45	37.8	5	1	1		.10	.51
Open and healed wounds combined	255	48.2	22	23	30	7.49	15.3	72.0

The 240 trees examined had altogether 255 open and closed wounds which led to 126 infections; that is, about 50 per cent of the wounds became infected. Not all infections are of a serious nature, but 75, or 60 per cent, led to cull. Of these 75 cases of cull, 70 per cent present heavy loss (xx and xxx), while 30 per cent are still in the initial stages. The decay (net cull) coming from infections through wounds, open and healed, amounts to over 15 per cent of the total merchantable volume of the trees analyzed. The actual loss (direct cull) due to the wounds themselves is very slight, a little over one-half of 1 per cent of the total merchantable volume. Open wounds have an infection rate of 51 per cent as compared with 38 per cent for healed wounds, and their cull rate is very high. Decay traceable to open wounds amounts to 15 per cent of the total merchantable volume. Healed wounds led to only negligible loss.

Fire is beyond comparison the most frequent and the most consequential of all the many causes of open wounds found in aspen. For a clear understanding of the rôle of forest fires it is necessary to note that the area studied has not suffered much, relatively, from fires, although in no decade of the nineteenth century has it been entirely exempt from burns. The fire damage is practically on a par with that prevailing throughout the aspen stands in central Utah. Aspen is a short-lived species, so that the oldest record from the area does not go back farther than 1771. The only severe fire of the nineteenth century occurred in 1867. The seventies, eighties, and nineties each had occasional light fires. A single scar dates from 1903.

Only the younger age classes are practically free from fire wounds. They have grown up since the last serious fire occurred in 1867. For purposes of analysis, the open fire wounds are roughly graded according to their size, their depth, and the effect they are likely to have on the physiology and mechanical strength of the tree. The cases of cull to which the infections lead are similarly rated according to their importance. Even of the small fire scars over 76 per cent are infected. Larger scars are infected at the rate of 88 per cent and the largest at the rate of 108 per cent. Occasionally a single large fire scar gives rise to more than one infection.

The infections originating from fire scars are likely to be of an injurious nature, as will be seen from the following tabulation:

Infections starting from small fire scars:
- 46 per cent lead to cull;
- 38.5 per cent lead to heavy cull.

Infections from medium-sized fire scars:
- 78.5 per cent lead to cull;
- 54 per cent lead to heavy cull.

Infections from large fire scars:
- 84.5 per cent lead to cull;
- 81 per cent lead to heavy cull.

In other words, the greater the injury to the tree from fire the more cull, and the more serious cull, results.

The amount of cull due to decay entering through fire scars is closely related to the ages of the trees. The first loss from cull, one of 3.5 cubic feet, appears in the 71–80-year age class. The volume of cull increases slowly until in the 101–110-year class it suddenly rises to 14.5 cubic feet. For the next age classes, 111–120 and 121–130, cull volumes of 56.5 and 52 cubic feet, respectively, are recorded. The total cull from decay traceable to fire scars amounts to nearly 180 cubic feet, or 14.5 per cent of the total merchantable volume (see Table 1). It represents 68 per cent of the total loss from gross cull. The direct loss chargeable to the scars themselves amounts to only 2.8 per cent of the total gross cull, a negligible quantity when compared with the indirect loss resulting from infection and decay starting in fire scars. The extremely high cull per cent bound up with the physical presence of fire scars confirms and emphasizes the findings of similar detailed analyses of white fir and incense cedar. The indirect damage caused by forest fires is far greater than appears at first glance.

Fire is a more or less controllable factor in forest management. The extraordinary sensitiveness of the thin-barked aspen to fire injury and the great danger of the trees becoming infected through fire wounds make it imperative that aspen be protected even from light fires.

Next to fire scars in frequency of occurrence are bruises caused by falling trees and limbs. The thin bark of aspen renders the species particularly liable to wounding from this source, but the infection rate lags far behind that of fire wounds. A bruise is superficial and at most exposes only the sapwood. The underlying heartwood is protected from infection with the most destructive fungi until the cover of sapwood begins to check badly and finally disintegrates. Bruises are commonly infected, but only in rare cases does the infection lead to actual loss. Dead and broken tops show a surprisingly low infection rate, and such infections rarely result in cull. The highest infection rate, after that of fire scars, is found in "ingrown stubs," that is, broken-off and partly overgrown remnants of limbs and forks in the lower part of the bole; but as a source of cull the infections are negligible. Lightning seems to injure quaking aspen only rarely. Not more than two lightning scars were found in the area studied, and neither became infected. Smaller wounds of various origin were not infrequently accompanied by secondary decays, which have no bearing on the loss factor.

Of all infections, those by *Fomes igniarius*, the most energetic destroyer of the wood of aspen, are by far the commonest. About one-third of these enter through fire wounds, one-third through bruises and cankers, and the rest through knots, roots, and minor wounds. In practically all cases, stringy butt rot entered through fire scars.

RÔLE OF CANKER

The frequency with which canker occurs in Utah made it desirable to determine in detail the rôle played by this injury in the pathology of aspen. (Table 2.)

In so far as it exposes the wood, canker would be comparable to a wound, in the current sense of the word, were it not for one fundamental difference: A wound presents the largest surface of unprotected wood immediately after it comes into being. From that time on, callus formation in the natural healing process tends to cover up the exposed surface until the wound is closed. The chances of infection are on the decrease until they cease to exist with the healing of the wound. Canker, on the contrary, increases in size with age, owing to the successive killing back of the calluses as they are formed. The risk of infection is cumulative. Only occasionally is a smaller canker healed over. (Table 2, columns 4, 5, and 6.)

TABLE 2.—*Number of cankers and relation to infection*

Age class	Number of trees (basis)	Percentage of trees with canker	Type of cankers			Direct cull from canker	Cull from rot entering through canker
			Small	Medium	Large		
			Number	*Number*	*Number*	*Cubic feet*	*Cubic feet*
30–40 years	15	13	2	1	----------	----------	----------
41–50 years	20	5	----------	1	----------	----------	----------
51–60 years	33	18	7	[1]	4	0.71	2.39
61–70 years	12	25	3	2	6	3.00	----------
71–80 years	31	13	[2]	2	----------	----------	----------
81–90 years	35	31	[3]	9	8	11.65	.30
91–100 years	21	38	3	8	8	.91	6.03
101–110 years	20	30	[4]	6	1	----------	1.83
111–120 years	22	41	[5]	7	1	.15	.07
121–130 years	14	36	6	6	7	4.46	16.04
131–140 years	7	57	4	4	3	7.24	----------
141–168 years	10	40	[6]	3	5	----------	----------
Total	240	26	[7]	[8]	[9]	28.15	26.66

[1] 5 open, 1 healed.
[2] 2 open, 1 healed.
[3] 1 healed.
[4] 4 open, 2 healed.
[5] 4 open, 1 healed.
[6] 1 healed.
[7] 35 open, 6 healed.
[8] 54 open, 1 healed.
[9] 43 open.

Beyond generalities little is known regarding the occurrence of cankers. On the area investigated, 63 trees out of a total of 240 had 139 cankers, of which 132 were open and only 7 healed. The direct cull caused by the cankers themselves amounts to a little over 2 per cent of the total merchantable volume, or a little over 10 per cent of the total gross cull. The latter relation classes canker as a far less negligible type of injury than fire scars.

On the other hand, out of 139 cankers only 26 became infected, and while these led to 11 cases of cull, not more than 6 resulted in serious decay. The entire net cull from rot traceable to canker amounts to only a little over 2 per cent of the total merchantable volume, or 10 per cent of the total gross cull—about the same as the direct cull from canker. Considering the apparently very favorable conditions for infection as presented in the aggregate by the relatively large surface of exposed wood in cankers, these figures are surprisingly low. It is not impossible that the peculiarly stained and brittle wood often underlying the cankers presents an uncongenial medium for the fungi attacking aspen.

An analysis of columns 1 and 3 of Table 2 indicates that the occurrence of canker is not so much a matter of age as of size of the trees. Every age is subject to canker, but the percentage of trees attacked increases with some regularity with increasing age. Canker is rarely a cause of top killing in large trees. Only three such cases were observed.

From the foregoing it appears that canker is not an important factor as an indirect cause of decay. Its rôle in the pathology of aspen reduces itself to many partial girdlings on bole, branches, and twigs and to the increased difficulty of barking in utilization for pulp; but these items are collectively of sufficient weight to warrant further and more intensive studies of the origin and life history of canker with a view to possible control.

65250—29——3

RELATION OF CULL TO VIGOR OF TREE GROWTH

Former studies in white fir had indicated that the loss from injurious factors was not independent of the vigor of tree growth as expressed by the relation of the tree volume to the standard volume for the same age (see p. 10). In Table 3 the trees are segregated and tabulated in 10-year age classes according to their relative volume. For this purpose only those trees which deviate considerably from the standard are considered. Trees a little above or below are evidently too close to standard to be maintained in separate groups. Though this procedure leaves only small bases for the individual age classes, they are sufficiently large to indicate certain tendencies and relations. The net cull per cents due to rot do not increase steadily with age. There is a marked and sudden jump, which occurs for the trees much above standard in the 101–110-year age class, but for those much below standard, 10 years earlier in life. The same relation is reflected in the total net cull (last column) from all causes, though it is somewhat disturbed by the canker figures. In Table 3 the main sources of cull are listed separately. *Fomes igniarius* (F. i.) stands out as the most important individual factor. *F. applanatus* (?) and secondary fungi seem to find in quaking aspen only a moderately congenial host.

Table 3.—*Net cull per cents of total merchantable volume in 10-year age classes*

TREES MUCH ABOVE STANDARD

Age class	Number of trees (basis)	Net cull (per cent)						
		From rot				From canker	Misc.[4]	Total
		F. i.[1]	F. a.?[2]	Sec.[3]	Total			
Years:								
30–40	4	----	----	----	----	----	----	----
41–50	----	----	----	----	----	----	----	----
51–60	13	6.14	----	----	6.14	1.84	0.05	8.03
61–70	4	----	----	----	----	12.50	----	12.50
71–80	6	.42	3.25	----	3.67	----	.10	3.77
81–90	14	1.42	----	----	1.42	----	.10	1.52
91–100	3	2.46	----	----	2.46	----	.35	2.81
101–110	3	10.82	11.61	----	22.43	----	.66	23.08
111–120	7	37.10	4.53	----	41.63	----	.79	42.42
121–130	1	39.10	----	----	39.10	----	.94	40.04
131–140	3	1.67	----	----	4.67	----	1.27	5.94
141–168	----	----	----	----	----	----	----	----

TREES MUCH BELOW STANDARD

Age class	Number of trees (basis)	F. i.	F. a.?	Sec.	Total	From canker	Misc.	Total
Years:								
30–40	2	23.82	----	----	23.82	----	1.59	25.41
41–50	13	----	----	----	----	----	----	----
51–60	17	----	----	----	----	----	----	----
61–70	4	----	----	----	----	0.94	----	.94
71–80	21	1.28	3.94	----	5.22	----	.01	5.23
81–90	16	2.09	.72	3.95	6.76	2.90	.48	10.14
91–100	9	16.46	6.21	8.09	30.76	1.87	.20	32.83
101–110	12	9.32	3.62	.21	13.15	----	.18	13.33
111–120	5	13.78	----	----	13.78	1.16	1.01	15.95
121–130	5	26.69	----	----	26.69	4.58	.24	31.51
131–140	4	17.44	----	----	17.44	14.51	----	31.95
141–168	2	24.70	13.27	.05	38.02	----	8.98	47.00

[1] F. i. *Fomes igniarius.*
[2] F. a.? Stringy butt rot (*Fomes applanatus*?).
[3] Sec. Secondary fungi.
[4] Misc. Direct cull from fire scars, frost cracks, incidental wounds, etc.

CULL PER CENTS

The preceding sections deal with the analysis of the injurious factors active in aspen and their mutual relations and lead to an understanding of the processes which in the end result in economic loss.

Table 4 expresses this economic loss as gross cull computed for each 10-year age class. The total apparent merchantable volume of all trees cut is 1,237.3 cubic feet. The total volume of gross cull is 264.6 cubic feet, or 21.4 per cent. In other words, in cutting aspen for pulp in the unmanaged forest on types corresponding to that of the region studied, a general allowance of 21 per cent must be made for cull from all causes. Of this cull by far the greatest amount, or more than 18 per cent, is directly traceable to rot. Canker follows next, with only 2.25 per cent, and miscellaneous causes for cull, such as fire scars, wounds from falling trees, etc., are accountable for less than 1 per cent.

The basis of trees arranged in 10-year age classes is rather weak from 131 years on. The last group, 141–168, is supported by only 10 trees scattered over 27 years. The cull per cent from all causes for the well-supported age classes from 30 to 130 years reaches 21, thus hardly differing from the cull per cent of all ages up to 168.

TABLE 4.—*Cull per cents in 10-year age classes with gross cull charged to all causes of cull*

[Miscellaneous gross cull includes the direct cull from fire scars, frost cracks, incidental wounds, etc.]

Age class	Number of trees (basis)	Total merchantable volume	Gross cull: From rot: Volume	From rot: Percentage of merchantable volume	From canker: Volume	From canker: Percentage of merchantable volume	Miscellaneous: Volume	Miscellaneous: Percentage of merchantable volume	Total: Volume	Total: Percentage of merchantable volume
		Cu. ft.	*Cu. ft.*		*Cu. ft.*		*Cu. ft.*		*Cu. ft.*	
30–40 years	15	10.32	0.14	1.36	--------	--------	0.01	0.09	0.15	1.45
41–50 years	20	12.82	--------	--------	--------	--------	--------	--------	--------	--------
51–60 years	33	52.78	2.47	4.68	0.74	1.40	.02	.04	3.23	6.12
61–70 years	12	36.05	2.11	5.86	3.00	8.33	.02	.06	5.13	14.23
71–80 years	31	65.13	3.65	5.60	--------	--------	.10	.16	3.75	5.76
81–90 years	35	173.79	5.23	3.02	11.38	6.55	.28	.16	16.89	9.73
91–100 years	21	118.89	13.64	11.48	.91	.77	.33	.28	14.88	12.53
101–110 years	20	116.11	21.01	18.11	--------	--------	.42	.36	21.43	18.47
111–120 years	22	214.03	56.68	26.49	.15	.07	1.93	.90	58.76	27.44
121–130 years	14	176.89	73.46	41.48	4.46	2.52	1.33	.75	79.25	44.75
131–140 years	7	88.04	9.07	10.30	7.24	8.23	2.62	2.98	18.93	21.50
141–168 years	10	172.45	38.89	22.54	--------	--------	3.31	1.92	42.20	24.46
Total	240	1,237.30	--------	18.29	--------	2.25	--------	.84	264.60	21.38

The percentage of the gross cull from rot alone (Table 4, column 5) shows a steady increase which changes to a sudden rise with the 91–100-year age class and reaches over 41 per cent in the 121–130-year age class. A similar increase appears in the total gross cull per cents, though without the regularity of the increase in rot gross cull, influenced as they are by canker gross cull, a factor which has little to do with age. Both young and old trees are subject to canker attack, and, given the same size of canker, the smaller the bole the heavier the damage.

It is evident that the cull per cents do not apply to area but to merchantable volume alone and that they can be used only for stands composed more or less of the age classes here represented.

Since miscellaneous cull is a negligible factor and canker cull is not only erratic but evidently confined to definite regions and stands, the rot cull remains as the important and more or less uniformly applicable index of the relative soundness of aspen stands comparable to the one under investigation. When the representation of age classes in a given stand is known, the cull per cents for each age class can be used, due consideration being given to the modifying agencies discussed in the preceding sections.

DISCUSSION

The aspen problem in Utah resolves itself into the question whether the species is to be considered a weed tree, to be replaced as soon as feasible by more promising species, e. g. conifers, or whether it is to be put under management and regulation with a view to utilization for pulp wood. The choice depends on a number of considerations, prominent among which is the relation of cull to volume produced. If quaking aspen can be made to produce, in sustained yield, sound pulp wood in quantities sufficient to warrant harvesting at a profit, the mere fact that it is already on the ground will speak strongly in favor of retaining and fostering the species. Replacing large areas of one species with another, particularly on sites as little favorable relatively as those now occupied by aspen, is an enormous and very costly undertaking, fraught with many risks. It has been tried over and over again in Europe, where the practice, except in extreme cases, is now thoroughly discredited. Moreover, it would be rash to assume that the stands expected to take the place of aspen will be free from loss. To judge from the estimated cull per cent in neighboring coniferous forests, the loss from decay and other injurious factors in the new stands is likely to be considerable, particularly if the longer rotation that goes with management for saw timber is taken into account.

On the other hand, it will be futile to attempt the management of aspen for pulp wood unless the relation of loss to output is considered. The forester will be inclined to regard the loss as serious when it tends to offset the increment. At present the only agency likely to put aspen under management is the Government. As long as the Forest Service is not authorized to harvest timber on its own lands even when the cutting is imperative, the question will remain more or less academic. Timber on national forests can be cut only when a purchaser of stumpage is found, and the purchaser is not concerned with the rate of increment and its relation to the loss factor. He is solely interested in the question whether the amount of sound wood he can harvest from a given unit will pay for his operations and leave him an adequate profit. Loss to him means something entirely different from what it means to the professional forester, and his concepts will dominate at least in the immediate future.

HARVESTING VIRGIN TIMBER

Just where the future purchaser of aspen pulp wood will draw the line it is impossible to say. Too many factors enter into the equation. But the knowledge of the cull per cents will help him to weigh the loss against expected output from regions similar to the vicinity of the Great Basin Range Experiment Station.

The data on which this bulletin is based cover the age classes from 30 to 130 years. The ages above 130 years are too weakly represented to be of much value. The trees analyzed do not represent one extensive all-aged stand, but are selected from a number of smaller, more or less even-aged groups, so that each class in the cull per cent table (Table 4, last column) gives at least a clue as to what cull per cent might be expected in virgin uncared-for aspen.

EVEN-AGED UNITS

Up to 90 years the percentage of cull from all causes is so low that it can not seriously affect the final output, though the loss through canker may introduce a disturbing factor. The cull per cent in the 91–100-year age class amounts to 12.5, which is undoubtedly well within reason from the point of view of the prospective purchaser. The 101–110-year age class, with over 18 per cent, may still prove attractive, while the 27.5 per cent gross cull of the 111–120-year class probably exceeds the limit of allowable loss, at least on the less accessible logging chances. The almost 45 per cent gross cull of the 121–130-year age class will render logging altogether unprofitable, even on the most accessible areas.

MANY-AGED UNITS

Aspen logging units in Utah are frequently made up of numerous smaller even-aged stands, presenting conditions analogous to those prevailing in the region studied. The cull per cent as a whole computed for all ages between 30 and 130 amounts to 21 and is therefore hardly high enough to act as a prohibitive deterrent, except perhaps on less accessible areas and under unfavorable logging conditions.

The greater the representation of the older age classes on a logging unit the greater will be the resulting cull per cent, and vice versa, as will be seen by comparison of the figures in Table 5. The arrangement of the table is self-explanatory. The merchantable volumes and the gross cull volumes for the combined-age classes were added separately and the percentages computed. In the first part of Table 5 (younger age classes prevailing) the first group is composed of the age classes 30 to 80. It is not to be assumed that stands much younger than 30 years old will be utilized. The second part of Table 5 shows the cull per cents of stands composed of older trees only, from 130 years downward to 70 years.

Table 5.—*Gross cull per cents in relation to age classes represented in the stand*

Age classes	Cull per cent		Age classes	Cull per cent	
	Total gross	Gross, exclusive of canker		Total gross	Gross, exclusive of canker
Younger age classes prevailing:			Older age classes prevailing:		
30–80	7	4	130–121	33	31
30–90	8	5	130–111	31	30
30–100	10	7	130–101	29	27
30–110	14	11	130–91	26	24
30–120	18	15	130–81	25	23
30–130	21	19	130–71	23	21

The desirability of a given tract depends, of course, not solely on a low cull per cent. Accessibility, quantity of merchantable timber per acre, and relative cost of handling small as compared with larger timber are important factors. But there can be no doubt that, other things being equal, a high representation of the younger age classes with their relatively small loss from cull will make a logging chance more attractive than a preponderance of the older classes.

The total gross cull is composed of cull from decay, cull from canker, and cull from miscellaneous causes. Of these three factors canker is the most erratic. It does not occur everywhere nor in equal intensity, and it is not directly progressive with age. Cull from decay, including miscellaneous causes, represents a far more stable factor. Although it would be going too far to assume that every stand of aspen, even if apparently similar to those in the region of the Great Basin Range Experiment Station, must show the same amount of decay per age class, it can be taken for granted that, over large areas, the variation in the cull from decay will not be considerable. Cull from miscellaneous causes, though also progressive with age, is only a minor factor, but the same causes that are at work on the area studied are present in other aspen forests. The last column of Table 5 illustrates the relation of cull from rot and miscellaneous causes to representation of ages in those stands in which canker is absent or rare.

It follows from the foregoing that, as far as the harvesting of virgin aspen is concerned, no working plan can be complete without a survey of available stands, both even aged and many aged, with regard to ages represented. The survey should take into account also the prevalence of canker, particularly in the younger age classes, where decay plays a minor rôle.

A survey of ages presents particular advantages in cruising timber for sale. The application of an arbitrary cull per cent to the cruise introduces gross errors, to the detriment of either the purchaser or the Government. Once the ages represented are known, it is an easy matter to determine, from the cull per cents per age class as given above, the actual relation of loss to output, within relatively narrow limits of error.

MANAGEMENT

So far the interests of the purchaser, not those of the professional forester, have been considered. The forester, not content with the disposal of existing virgin timber, is more deeply concerned with the establishment of improved stands and the perpetuation of maximum yield.

It is difficult to discuss questions of management and regulation when clear-cut definitions of both terms with relation to aspen, except in the abstract, are lacking. What form management will take in the aspen forest in the future, outside of fire protection, is open to guess. Improvement cutting on a large scale by means of timber sales—practically the only silvicultural practice now possible—is out of the question for aspen. It is more than probable that management in the aspen forests of Utah will consist in a first heavy utilization, followed by the slow establishment of adequately stocked even-aged or two-aged stands, which then may come under true management by a new generation of foresters. The present generation will, undoubtedly, have to deal with the wild, uninfluenced, unmanaged aspen stand, its protection and its utilization only. It will practice preservative rather than creative management. Nevertheless, the chances of success in the future depend on the measure of foresight and forethought bestowed to-day upon the aspen problem and the possibilities of constructive management.

The probable evolution of the management of aspen in Utah must follow the history of all conversions of virgin forests into managed forests and move in two successive steps: (1) The gradual replacement of the existing wild, highly defective, and many-aged forests by more or less even-aged second growth, uncared for except in so far as adequate fire protection decreases the number and size of fire scars and therewith the chances of infection (conversion or transition period), and (2) evolving progressively out of the conversion period final regulation on the principle of sustained yield together with systematic elimination of all controllable injurious factors.

Systematic and well-planned replacement of virgin timber by young growth is not possible on national forests under present conditions. Even sporadic replacement depends on the chance of finding a purchaser for a given block of timber; that is, it is incidental to a timber sale. The unit to be converted is not necessarily one of silvicultural choice. At best a compromise may be effected between pressing silvicultural needs and the contingency of disposing of existing timber by means of a timber sale. Thus the harvesting of virgin timber, which must precede management proper, is left more or less to chance.

NET VOLUME

Given the possibility of constructive action, the choice of the time at which the conversion should be inaugurated becomes a matter of consideration. From the point of view of economics as influenced by pathological factors, conversion should begin before loss becomes too heavy to make possible a timber sale, as the only means of conversion. What is left after the cutting represents the raw material for the next stand, and the infections present in the young growth are carried over into the conversion period. Figure 2 illustrates the progressive course of average decay volume and of average tree volume in 10-year age classes of a practically virgin stand, containing trees of all ages from 30 to 130 years. The age classes above 130 years are poorly represented and not of sufficient importance in so short-lived a species as quaking aspen to be included in the curves. The loss from canker likewise is not considered. Its bearing on the final output is of relatively small importance and must be judged separately in each case. From a practical point of view, neither the volume curve nor the decay-volume curve are relevant when taken individually. The volume curve regarded by itself is misleading, since it gives merely the apparent, not the true, merchantable volume. The decay-volume curve, on the other hand, may be ever so steep and reach ever so high, but in the final analysis the only criterion is the net volume, the difference between the apparent volume and the decay

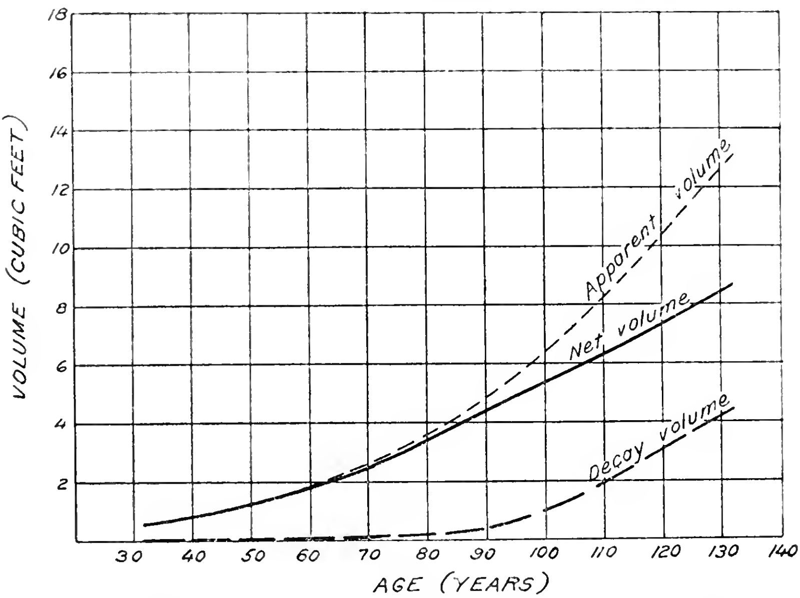


FIGURE 2.—Curves of apparent volume, decay volume, and net volume over age

volume. The net-volume curve makes it possible to gauge the actual amount of merchantable timber on the ground at given stages in the development of the stand. Following the apparent-volume curve fairly closely in the younger age classes, it begins to lag behind at about 90 years but still continues its upward trend.

NET INCREMENT

The actual ratio of decay volume to apparent volume is not the only consideration. Any attempt at regulation in the forest is futile without due regard to the rate of increment. Figure 3 illustrates the relationship between the apparent periodic increment and the periodic decay increment. Here again the criterion is the curve of net periodic increment; that is, of the difference between apparent periodic increment and periodic decay increment. The curve of apparent increment simply indicates the rate of increment for a hypothetically sound forest in which no loss at all occurs. The net-increment curve alone illustrates the actual profit over loss in 10-year periods. In the younger age classes the curve runs close to that of apparent increment. In the 70-80-year period it flattens out and thereafter remains practically at a level, far below the apparent-increment curve. From about 80 years upward there is no gain in net increment. The flattening of the apparent-increment curve occurs fully 40 years later, so that loss from decay brings about the same economic effect at 80 years which accompanies maturity and senility at 120 years.

When the representation of trees of different age classes is known, the net-volume curve affords a clue as to whether, at a certain time, the harvesting of a given stand will be profitable or not and serves

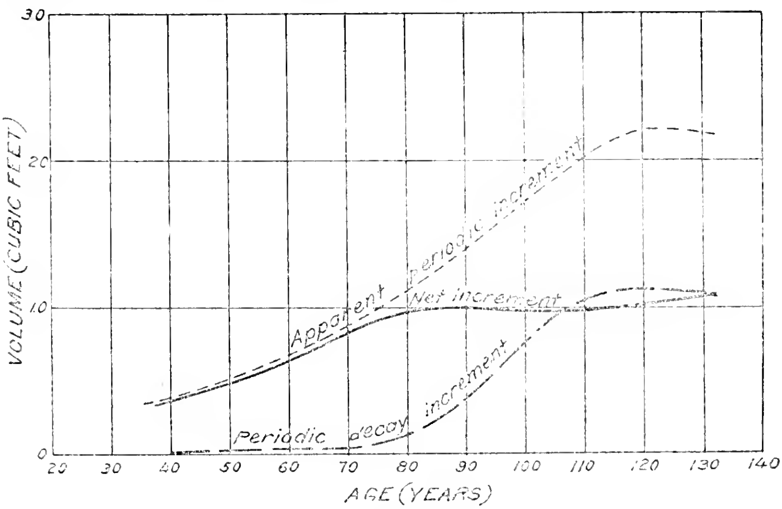


FIGURE 3.—Curves of apparent increment, decay increment, and net increment over age

as a guide in the choice of the most opportune time for harvesting (pathological felling age). The net periodic increment curve, on the other hand, does not concern itself with the accumulated wood capital but with the rate of the accumulation itself. Its flattening marks the phase in which stagnation begins. As long as decay in aspen plays a rôle similar to that it plays to-day—and it is not likely that during the conversion period a great change is to be expected—the culmination of the curve is the limiting factor which determines the pathological rotation.

It is the part of forest regulation to read from these curves just where the lower age limit for the interruption of the process should be placed and how long a given stand may be left uncut without undue loss. In managed forests the determination of the felling age and rotation are closely interrelated problems. When felling age and rotation are made the objects of speculation, such yield figures as may be obtainable are generally applied as though the loss factor did not exist. In the conversion of the virgin forest the felling age is the guiding factor, with rotation visualized in a far future.

Through the first cut the forest is brought into immediate touch with the generation or generations concerned with its management. For long-lived species this change in time relations reduces the perspective from centuries to a number of decades. Aspen is short lived. The life of the wild aspen forest as a whole does not reach much beyond 130 years, and if decay were absent that age might be chosen as the felling age for the first cut, though not for the rotation. The pathological rotation may be figured on a net maximum-volume basis or on the basis of rate of net increment. Both methods are closely related. They approach the same group of problems from different angles. In a former paper (*11, p. 59*) the writer has used the net maximum volume as the guiding factor, and Baker in his bulletin on aspen (*1, p. 15*) has placed the pathological rotation on the same principle at 110 years, following therein the data furnished in the writer's preliminary manuscript report. Weigle and Frothingham (*15, p. 31*) came to the conclusion that for aspen in the Northeast the maximum age the trees may be allowed to attain is fixed by the relatively early beginning of decay at approximately 80 years.

There are valid reasons for the use of the net maximum volume as a criterion for the choice of the pathological rotation. Its weakest point is that it is not sufficiently definite, at least for aspen. On the other hand, a strong case can be made for applying the rate of net increment. Here the evidence is clear and unmistakable.

The choice of both felling age and rotation is largely a matter of personal judgment and interpretation of data. In the following discussion the ratio between the net maximum volume and the rate of net increment is made the basis for the pathological felling age. For the pathological rotation the process is reversed. The rate of net increment is regarded as the decisive factor, due consideration being given to net maximum volume.

The steady rise of the net-volume curve in Figure 2 indicates that the accumulated net wood capital will support a logging operation at any time within the life of the stand, but the straightening out of the net-volume curve and its deviation from the apparent-volume curve makes it advisable to place the pathological felling age at about 80 to 90 years. The flattening of the net-increment curve (fig. 3) supports this view and limits the pathological rotation to about 80 to 90 years. Since it is not likely that longer rotations will be adopted for quaking aspen grown for pulp wood, the main conclusion is that the pathological factor in this species does not shorten either the felling age or the rotation to a point below that which is silviculturally desirable.

In the wild forest of unknown history it is difficult to determine ages over large areas. The practical forester still works with diameters, not with age classes. In Figures 4 and 5 the same elements as in Figures 2 and 3 are presented on a d. b. h. basis. The curve of net merchantable volume, after a satisfactory rise in earlier years, tends to flatten out after the trees have reached 12 inches d. b. h. The flattening of the curve is marked at 14 inches d. b. h. In Figure 5 the curve of net increment in merchantable volume rises rapidly to about 9 inches d. b. h., culminates at about 10 inches d. b. h., and

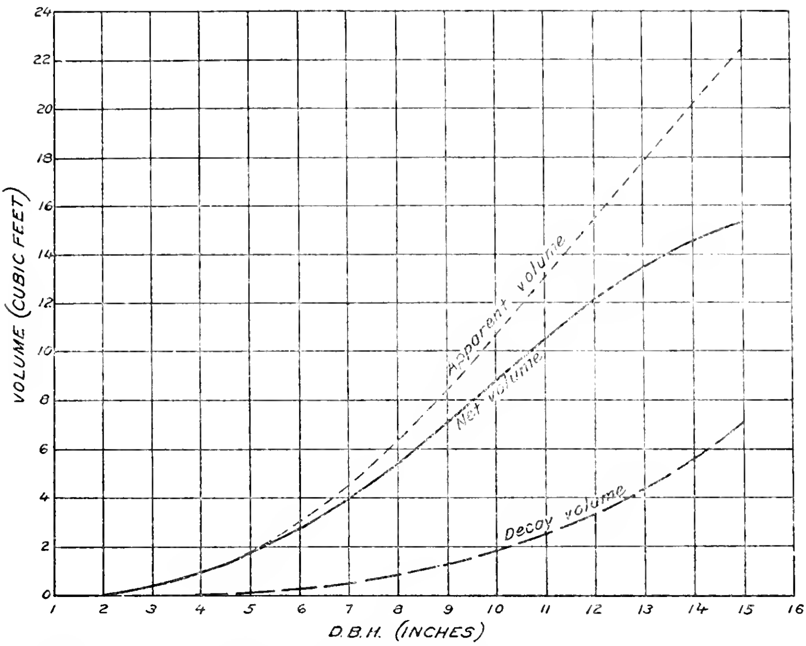


FIGURE 4.—Curves of apparent volume, decay volume, and net volume over d. b. h.

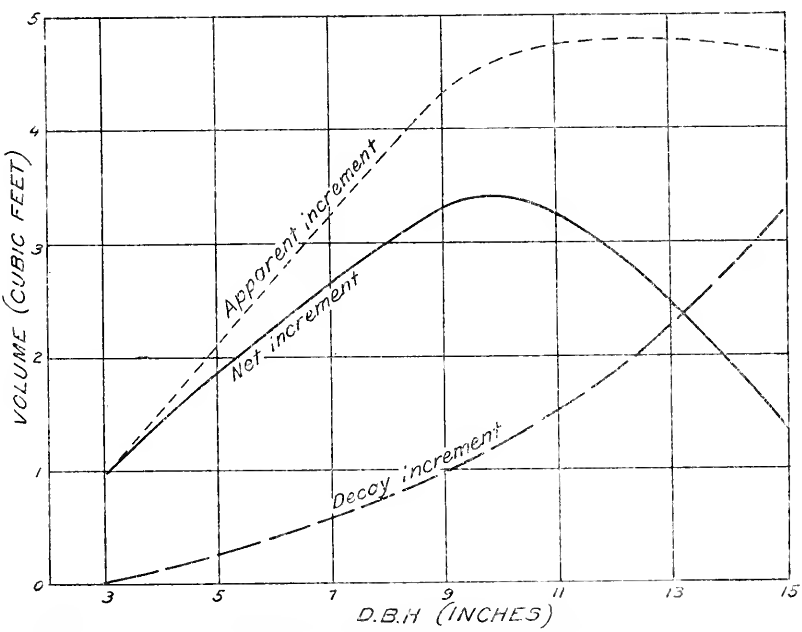


FIGURE 5.—Curves of apparent increment, decay increment, and net increment over d. b. h.

then drops almost in the same ratio. At 13 inches d. b. h. the net increment is not greater than it was at about 6.5 inches d. b. h. It is clear that in considerations of prospective yield the culmination of the curve at 10 inches d. b. h. offers an indication as to the management of a given stand, especially when judged in conjunction with the net-volume curve of Figure 4. On the basis of d. b. h., the pathological felling size—to coin a term corresponding to felling age—may be placed at about 12 inches. The pathological rotation is determined by the culmination of the net-increment curve at 10 inches d. b. h. While diameter is, broadly speaking, a function of age, the relation is too erratic to be reliable. Curves based on diameters can therefore serve only as a makeshift for use in questions of regulation.

It is here taken for granted that management of aspen is contemplated on the better sites, I and I–II, only. On poor sites aspen makes very slow and poor growth and reaches merchantable size at an age when the loss from cull is unduly high. The influence of growth has been illustrated by Table 3. Vigorous growth retards heavy loss by at least a decade. At best, aspen in Utah, even on the better sites, does not produce timber in such quantities that the loss factor can be disregarded in any scheme of management. The question is rather whether by proper management, including choice of sites, the loss can be minimized to such a degree that it does not make utilization unprofitable.

THE CONVERSION PERIOD

For the purposes of discussing the probable rôle of pathological factors in the conversion period, the outstanding results presented in the preceding pages are here summarized.

The principal direct causes of cull in aspen are decay (mostly from *Fomes igniarius*) and canker, or a combination of both. Cull caused by wood-boring insects does not lie within the scope of this study. Other causes of cull, such as fire scars, frost cracks, wind shake, and lightning scars, which are to be reckoned with in species of the saw-timber type, are practically negligible in pulp-wood timber. But as an indirect cause of cull one of these, fire scars, can not be overlooked. By far the greater part of cull has to be charged to decay, and much of this enters through fire scars, so that the latter are responsible not only for the direct loss from burning but for the indirect far greater loss from decay. The rate of infection of fire scars, even of smaller size, is very high, and the infections readily lead to heavy cull. There is a direct relation between number and size of fire scars and cull from decay. To a small degree, infection of the tree takes place through open cankers, and to an even smaller degree through bruises from falling trees.

Fires and fire scars are preventable to a certain degree. The elimination of fires will undoubtedly cut down cull from decay to a considerable extent. Canker can not be controlled until more is known about its cause. Bruises from falling trees and limbs not only induce decay but also stand in an indirect relation to the decay factor in so far as butt and root rots mechanically weaken the affected trees to such an extent that they are easily thrown over in heavy windstorms. When decay, coming from the bole, destroys the central wood cylinder of a larger limb, the thin shell of sapwood and bark is no longer able to carry the weight, and the limb breaks off. The elimination of decay in a stand necessarily cuts down windfall to a large extent and therewith the bruising of standing timber.

The occurrence of decay depends largely upon the number, size, and character of the wounds present, while the degree of decay depends partly upon the character of the wounds through which it enters, partly upon the age of the trees and their rate of growth, and finally upon the combination of these factors. Age is beyond doubt the most important. Decay is rare in the younger age classes and increases with age. From a certain age class onward decay becomes prevalent and later cuts heavily into the timber values produced. Canker, a minor factor, is not progressive with age in the same sense as decay.

With these facts in mind it will be possible to discuss the probable rôle of pathologic factors in the management of the future aspen forest.

As long as forest management is limited to relative, not absolute, protection from fire, to the slow harvesting of existing stands, and to the creation of second-growth, but wild, uncared-for stands necessarily partaking of the nature of the virgin forests they replace, the same losses must be expected during the conversion period, except that decay traceable to fire scars will decrease in the proportion in which fire-scarred individuals drop out and in which fire itself is kept out of the forests.

It will be a long time before all virgin aspen forests, even on the better sites, are fully and absolutely protected from fire. It is logical to assume, therefore, that for many years, at least, a large acreage will present conditions similar to those under which the existing stands have grown up. For these aspen forests the cull per cents determined from Table 5, their relation to relative volume growth (Table 3), and the effect of a combination of age, relative growth, and wounding, give at least a clue as to the proper time for disposal, depending on what is considered as serious loss from cull.

It may be argued that, since the prevention of forest fires will automatically reduce rot in standing trees to a minimum, decay will no longer constitute a limiting factor, even in the higher age classes. If this were correct, loss from decay would be unknown in those intensively managed forests of Europe from which fires are practically excluded. It is true that in European forests under the most perfect type of management such losses as are of common occurrence in this country are unknown; yet no forest in Europe is free from decay and cull. Intensive cultivation is the consequence of high valuation of timber, and the more valuable the product the more detrimental are losses which in less valuable timber would be completely overlooked. Thus, what in the present study is considered as minor or even negligible cull, rises to the rank of serious loss with the rise in value of the timber itself. The general trend in the valuation of all commercial timber is upward, and the change is particularly noticeable in this country with regard to a number of so-called inferior species, which not long ago were not cut at all, but which now find a ready market.

Aspen in Utah, if ever it moves up into the rank of a profitable source for pulp wood, will not escape the general tendency. As a necessary corollary the loss factor will be increasingly emphasized, and the minor decays, cankers, etc., which now are hardly noticed, must command relatively the same attention that is given to-day to heavy rot coming in through fire scars. If this reasoning is correct, it may be assumed that in the future much lower cull per cents will exert a limiting influence in the determination of the felling age.

FINAL REGULATION

Unless management culminates in regulation through control of the injurious factors which have caused the defective condition of present stands, the new growth will revert to the same virgin defective type.

Intelligent control of detrimental factors, whether influencing the increment or destroying actual wood values, characterizes the progress from the first steps in conversion to final regulation. Regulation aims at the greatest possible production of high-grade timber per unit in sustained yield, a goal that is unattainable unless at the same time those injurious elements are kept in check that either affect the increment or cause loss in the form of cull.

Fortunately the most prominent of all factors connected with cull, namely age, is subject to control through the choice of rotation. A very short rotation would reduce cull to a negligible figure, but at the expense of remunerative volume production. Since absolute control of all cull factors is impossible, sane regulation will attempt to strike a balance between highest possible volume production and unavoidable but not economically prohibitive loss.

The first effect of regulation must show itself in the decrease of the number of slow-growing, suppressed, and wounded trees, so that the combination of these factors gradually becomes less frequent.

CONTROL OF INJURIOUS FACTORS

That well-planned and judicially executed control measures can very materially improve aspen forests is undoubtedly true. The most urgent control measures, next to prevention of fires and adjustment of the age factor through rational determination of felling age and rotation, must be the periodic cleaning of the forest by elimination of the sources of infection, on one hand, and of individual trees most subject to infection, on the other. It should go without saying that trees with evident infection, especially those with sporophores of wood-destroying fungi, have no place in the regulated forest.

In this connection attention is called to infected aspen stumps, snags, and windfall. Both *Fomes igniarius* and *F. applanatus* are capable of living saprophytically on dead aspen wood and roots. They find favorable conditions for development and fruiting in stumps and dead trees, from which infection may spread to hitherto sound neighboring individuals. Impossible as the grubbing of aspen stumps appears at present, the protection of commercially valuable stands may ultimately necessitate the practice in the future. Meanwhile insistence upon cutting to low stump heights will reduce to a minimum the wood mass available for saprophytic growth. Offal resulting from control work, such as stumps, windfall, scraps, and infected wood, should not be permitted to remain lying in the woods. All such material should be destroyed by burning.

In control measures of this type the size of the unit treated influences their effectiveness, at least with respect to sporophores. The disposal of stumps, snags, and windfall is a protective measure which immediately benefits even the smallest stand. It eliminates an abundant source of direct infection of neighboring trees and clears the ground for young trees. To destroy sporophores or even sporophore-bearing trees on small areas, however, except as a matter of principle and routine, is not worth the trouble and expense. Spores are extremely small and light and are carried by air currents for long distances. For this reason the systematic eradication of sporophores can be advocated only when large areas are taken under treatment. The number of spores liberated from a single sporophore is immense, and a thorough plugging of this main source of infection over a large area could not but have a beneficial effect. But since it is impossible to extend the practice over all aspen stands, including those on poorer sites, the eradication of sporophores on the area treated is not equivalent to eradication of all spores which might be carried in from the outside. The danger of infection is materially lessened, but not totally absent, just as in insect control an epidemic is materially reduced without absolute extinction of all individuals.

Effective improvement, therefore, must include the removal of trees with wounds of a character likely to become infected. Here fire scars stand in the first line. The larger and deeper the scar the more imperative is the removal of the tree. Large bruises follow next. They are to be rated below small fire scars. Trees with large cankers on the boles should not be tolerated. Even small cankers on limbs, while not immediately impairing merchantability, affect the increment and are likely to spread to the boles. Intensive control may in some cases even have to resort to the pruning of cankered limbs.

Listing control measures in the regulated forest in accordance with their relative importance, the elimination of infected living and dead trees comes first, then that of wounded trees, and finally that of cankered trees and limbs.

It is not likely that frequent improvement thinnings will be practiced in aspen forests. Where only one or two such thinnings are contemplated during the life of the stand, the length of the period likely to elapse between the act of cleaning and final utilization governs the relative urgency of the control measures. The longer a wound remains open the greater is the chance of its becoming infected, so that the probability of infection steadily decreases with the approach of the final cut. The elimination of wounded trees is, therefore, more immediately urgent in the earlier than in the later part of the life of the stand, due weight being given to the size and character of the wounds. Trees already so badly infected that the symptoms of decay are readily detected should, as a matter of course, be cut at any time, but in view of the fact that increasing age strongly aggravates the decay factor, it would be a singular mistake to leave infected trees in older stands uncut on account of utilization drawing near. The older and bulkier the trees, the greater is the probability that in the remaining years decay will destroy considerable volumes of potentially merchantable timber.

In the control of canker and the cutting of trees with bruises, the age factor must equally be taken into account. In certain cases the combination of two or more minor injuries on the same tree—as, for example, a smaller fire scar and canker on the bole—will stamp the individual as undesirable in the regulated forest.

SUMMARY

Quaking aspen covers large areas of the national forests in Utah. At the present time it finds practically no use as a timber tree. The problem presents itself whether aspen should be replaced by more promising species or placed under management for possible utilization as pulp wood. Management involves protection and gradual replacement of the present wild forests by second growth, looking toward regulation. Replacement is possible only through utilization of old growth and is dependent upon the chances for timber sales. For timber sales the cull per cent to be charged against the apparent volume must be known.

The present study covered a representative area located at an elevation of 8,750 feet near the Great Basin Range Experiment Station in the Wasatch Range of the Rocky Mountains.

Cull is low in the younger age classes and increases with age, at first slowly, until in the 91–100-year age class a sudden and marked increase occurs. Relative vigor of growth, expressed in the relation of the tree volume to standard volume for the same age, exerts a modifying influence. In trees above standard the marked increase takes place in the 101–110-year age class; in those below standard, 10 years earlier. Cull from decay depends largely upon size and character of wounds. About 50 per cent of the wounds become infected. Fire scars are the most important type of wounds. They commonly lead to infection and heavy cull. The total cull from decay traceable to fire scars amounts to almost 15 per cent of the total merchantable volume and represents 68 per cent of the total loss from gross cull. A common canker of unknown origin unfavorably influences the increment and distorts the boles. Of 240 trees analyzed, 63 had in the aggregate 139 cankers, of which only 26 were infected. Of these infections only 6 led to considerable cull.

The merchantability of a given stand depends partly upon apparent volume, accessibility of the stand, and logging facilities, and partly upon the cull per cent to be deducted from the apparent volume. What will constitute a permissible cull per cent in a given case is a matter of judgment. The general cull per cent for the area studied, representing approximately Site I–II and comprising ages from 30 to 130 years, is 21 per cent, largely consisting of decay from *Fomes igniarius*. The age class 101–110 years has a cull of 18.5 per cent; the class 111–120, 27.5 per cent; and 121–130, 45 per cent. It is recommended that existing stands to be offered for sale be surveyed with regard to age, since cull bears a direct relation to age. After the improvement of a given unit through timber sales and after the establishment of second growth, the elimination of fires—and therewith of fire scars—will contribute largely to the lowering of the cull per cent due to decay; but with increase in the valuation of the timber itself, discrimination against minor cull will also become intensified.

Unless management culminates in regulation through control of the injurious factors which have caused the defective condition of present stands, the new growth will revert to the same virgin defec-

tive type. Regulation is the process of converting the defective virgin forest into the improved, cultivated forest. Final regulation requires active control of injurious factors through elimination of infected trees as sources of infection and of trees most likely to become infected on account of wounding.

On the basis of net volume production and net increment, both the pathological felling age and the pathological rotation lie at about 80 to 90 years. From the point of view of economics as influenced by pathological factors, it appears possible to raise quaking aspen in the intermountain district for pulp, because the silvicultural rotation will in all probability be shorter than the pathological rotation.

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UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

A METHOD FOR DETERMINING THE COLOR OF AGRICULTURAL PRODUCTS

By DOROTHY NICKERSON,[1] *Color Technologist, Bureau of Agricultural Economics*

CONTENTS

METHOD OF APPROACH TO A COLOR PROBLEM

There are two distinct methods for measuring color. By one method the stimulus of any color may be completely specified in terms of intensity at each wave length or frequency, or partially specified in terms of secondary standards. By the other method colors may be matched by the use of secondary standards and specified in terms of color, not in terms of the stimulus.

According to the report of the colorimetry committee of the Optical Society of America for 1920–21 (*9*),[2] [3] color is "the general name for all sensations arising from the activity of the retina of the eye and its attached nervous mechanisms, this activity being, in nearly every case in the normal individual, a specific response to radiant energy of certain wave lengths and intensities." The report says, further, that color "is fundamentally a psychological category," which means that we can not see wave lengths but that we can see color. To measure color we must deal with it psychologically—in terms of what we see, not in terms of the wave-length stimulus.

Color may be completely specified in terms of three attributes: Hue, brilliance, and chroma. Hue is the attribute which permits colors to be classed as reddish, yellowish, greenish, or bluish; brilliance is the attribute by which a light color is distinguished from a dark color; and chroma is the attribute by which a strong color may be distinguished from a weak color. Each of these attributes may be measured on a scale of psychologically equal steps.

[1] The author wishes to acknowledge indebtedness to C. F. Welsh, Bureau of Agricultural Economics, whose assistance in setting up and calibrating the various instrumental units used in this study was invaluable.

[2] This report is doubtless the best reference guide for a general study of color science that is available. The bibliography is excellent. Reprints may be obtained from the secretary of the Optical Society.

[3] Italic numbers in parentheses refer to "Literature cited," p. 32.

The report of the colorimetry committee (*9*) defines these attributes as follows:

Hue is that attribute of certain colors in respect of which they differ characteristically from the gray of the same brilliance and which permits them to be classed as reddish, yellowish, greenish, or bluish.

Brilliance is that attribute of any color in respect of which it may be classed as equivalent to some member of a series of grays ranging between black and white.

Chroma [4] is that attribute of all colors possessing a hue, which determines their degree of difference from a gray of the same brilliance.

Regarding the measurement of color:

The three attributes of color can be treated as quantities and specified numerically, if all discriminable colors are conceived to be arranged into a system such that neighboring members differ from one another in each of the three attributes by just noticeable degrees. Such a system is necessarily three-dimensional, and three ordinal values representing the positions of a given color in the several dimensions are needed to define the color.

With such a definition of color and its attributes, and with a method of measurement so obvious in its simplicity, it would seem that any colorimetric method of measuring color to be employed in standardizing and studying a series of colors should be based on measurements of hue, brilliance, and chroma.

Both spectrophotometric and colorimetric measurements may be made in different ways. Circumstances may make one type of color measurement preferable to any other. Therefore before a method is chosen the problem should be carefully studied. If the problem concerns the specification of colors already produced, so that one can record what they look like, or if it concerns colors which are not to be combined to produce new colors, then it is probable that descriptive color measurements are desirable—that is, measurements in terms of hue, brilliance, and chroma. But if the problem concerns the stimulus of the color, how it is produced, which wave lengths are most highly reflected, and how the colors will combine to produce new colors, then stimulus measurements are desirable—that is, measurements in terms of intensity at each wave length or group of wave lengths. The question to be decided in any color problem is this: Are color measurements or color-stimulus measurements the thing wanted?

COLOR PROBLEMS IN AGRICULTURE

The element of color is an integral grading factor in numerous standards established for agricultural products. Cotton, for instance, is sold according to grade and staple. The grade factor consists of three variables: Color, leaf and trash, and preparation or ginning. Hay is graded on color, foreign material, and condition. Color is an important element in grading fruits and vegetables; it is a part of the specifications for cotton-linters standards; it plays a part in grading rice, honey, meat, grains, breads, mayonnaise, and innumerable other agricultural products, or products made from those of agriculture, often with direct correlation in protein content, diastatic activity, or money value.

[4] "Saturation" is the term the report uses, with "chroma" given as a synonym. "Chroma," by definition, carries no other meaning, whereas "saturation" is often used to mean freedom from mixture with either white or black. See Webster's Dictionary, "Color", also Century Dictionary. (It has been suggested that chroma be used to cover those colors which exhibit hue, to contrast the term chroma with gray, or neutral colors—grays and chromas, for instance—but this use is very limited. For discussion of the subject see (*9, footnote p. 531*).

Since color is an important grading factor, it is necessary that a measure be made of color itself. Standards may thus be kept constant from year to year, the real importance of color as a factor of utility may be determined, and the intervals at which color gradations are fixed in the standards may be specified according to such determinations.

The aim of this bulletin is to describe a method of measuring color in agricultural products; to set forth the reasons for using this method, and to give needed illustrations of its use. The purpose is to aid others who have color-measurement problems to determine whether this method is fitted to their use and if so to give them an adequate description to indicate how it may be adapted and how it should be limited.

METHOD OF WORKING OUT A COLOR PROBLEM

ISOLATION OF COLOR PROBLEM IN COTTON STANDARDIZATION

The measurement of cotton has been chosen as a definite example of how this method may be applied, and will be used as such throughout this study except in so far as additional information may be brought out by other products. This does not mean that all of the work has been done on cotton alone. Considerable work has been done on hay color, and a satisfactory set of tables has been developed for determining grade from the color readings. In fact, the work on hay is the pioneer work of the method described.[5] Cotton, however, has been subjected to several methods of color measurement, and more phases of the subject of color and its application to color problems in agriculture can be illustrated in this bulletin by using cotton as the example.

The purpose of the study of cotton color is to isolate and measure the color factor in grading cotton, in order: (1) To insure constancy of the color element in the standards for grade (*a*) by making it possible scientifically to detect any variations which may occur, and (*b*) by making possible a series of exact color specifications for the various grades. (2) To determine the relationship between color in raw cotton and the color of yarns and fabrics in their "gray," bleached, dyed, and mercerized states. (3) To lay a foundation of fact material under item 2 upon which to determine how great emphasis should be given to color as a factor in the utility of raw cotton and whether fewer or more gradations of color in the standards would be desirable from a practical standpoint. (4) By an examination of properly selected samples of the crops of cotton actually produced from year to year to determine the limits of color variation in American cotton and the colors of most frequent occurrence, thereby providing a fund of statistical data from which to determine with accuracy how the standards for color should be pitched.

In approaching this problem there are factors peculiar to cotton which must be taken into consideration. There is, for instance, a very narrow range of color from the high to the low grades, and an exceeding fineness of differentiation which is ordinarily made by the cotton classer. Then, too, the cotton surface exhibits considerable leaf, trash, spots, and stains which must be integrated in order to

[5] Initiated in 1924 by E. C. Parker, K. B. Seeds, and W. H. Hosterman.

make possible the measurement of a sufficiently large sample to be representative.

The physical standards, known officially as the universal standards for American upland cotton and adopted for use by all of the principal international cotton exchanges, consist of nine grade boxes of White cotton. There are also 5 grades of Yellow Tinged, 3 of Blue Stained,

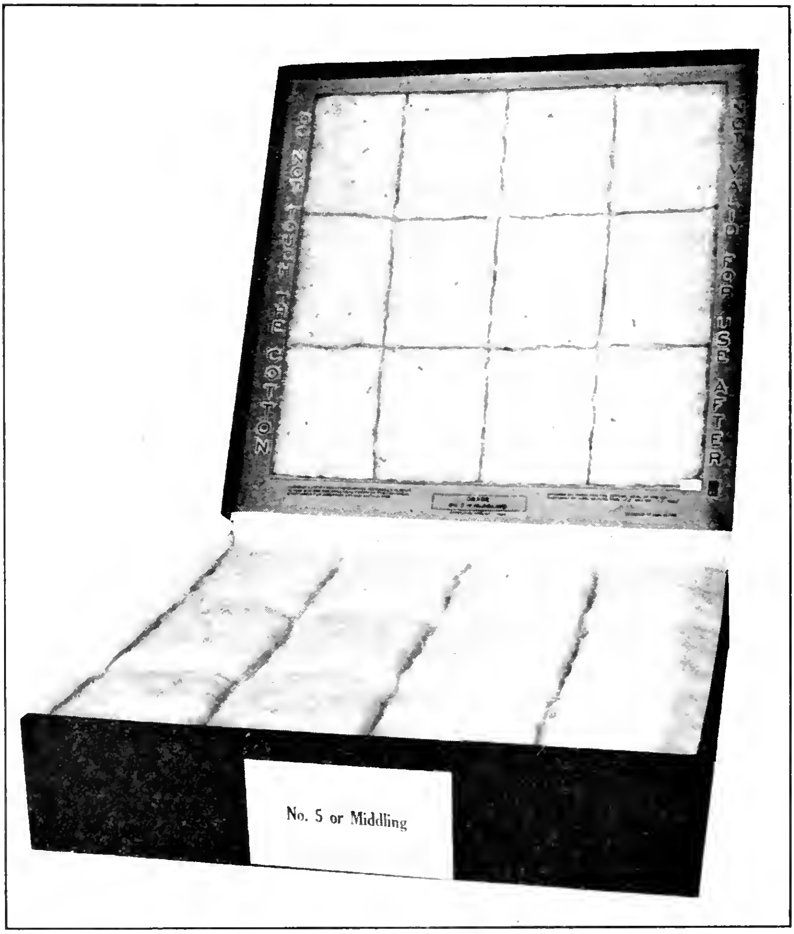

FIGURE 1. Practical form of the universal standards for the grade of Middling White cotton. A photograph is shown inserted in the cover of the box to verify the preparation of the cotton and the position of the leaf. At the bottom of the photograph appears the seal of the Department of Agriculture and the certificate and signature of the Secretary of Agriculture. Standards for the other grades and colors are represented in the same manner

and 5 recently established for Extra White. Copies, or what are known as practical forms, rather than the standards themselves, were used in the color work described in the following pages. Figure 1 illustrates the form of the standards. The relationship of the grades is shown in Figure 2. In each grade box there are 12 samples which represent the extreme variation allowable in that grade. The colors vary for each grade and for each position within the grade; yet each is definite and must be matched in all copies of the practical forms (*6*).

GRADE NUMBER AND ABBREVIATIONS	EXTRA WHITE*	BLUE STAINED (B)	*GRAY* DESCRIPTIVE (G)	WHITE	*SPOTTED* DESCRIPTIVE (S.P.)	YELLOW TINGED (T.)	*LIGHT STAINED* DESCRIPTIVE (L.S.)	YELLOW STAINED (S.)
1 OR M.F.				MIDDLING FAIR				
2 OR S.G.M.				STRICT GOOD MIDDLING		*STRICT GOOD MIDDLING*		
3 OR G.M.	GOOD MIDDLING	GOOD MIDDLING	GOOD MIDDLING	GOOD MIDDLING	GOOD MIDDLING	GOOD MIDDLING	GOOD MIDDLING	GOOD MIDDLING
4 OR S.M.	STRICT MIDDLING	STRICT MIDDLING	STRICT MIDDLING	STRICT MIDDLING	STRICT MIDDLING	STRICT MIDDLING	STRICT MIDDLING	STRICT MIDDLING
5 OR M.	MIDDLING	MIDDLING	MIDDLING	MIDDLING	MIDDLING	MIDDLING	MIDDLING	MIDDLING
6 OR S.L.M.	STRICT LOW MIDDLING			STRICT LOW MIDDLING	STRICT LOW MIDDLING	STRICT LOW MIDDLING		
7 OR L.M.	LOW MIDDLING			LOW MIDDLING	LOW MIDDLING	LOW MIDDLING		
8 OR S.G.O.				STRICT GOOD ORDINARY				
9 OR G.O.				GOOD ORDINARY				

* *THESE GRADES EFFECTIVE SEPTEMBER 1, 1928.*

═ *LIMITS OF TENDERABILITY FIXED BY CONGRESS MARCH 4, 1919.*

━ *LIMITS FIXED BY SECRETARY OF AGRICULTURE BY CONSTRUCTION OF FIFTH SUBDIVISION OF SECTION, UNITED STATES COTTON FUTURES ACT.*

●●● *LIMIT FIXED BY SECRETARY OF AGRICULTURE BY CONSTRUCTION OF REPORT OF HOUSE COMMITTEE ON AGRICULTURE ON AMENDMENT OF MARCH 4, 1919.*

FIGURE 2.—Grades and colors of the official standards for American upland cotton

EXPERIMENTS TO DECIDE UPON A METHOD OF MEASURING THE COLOR OF COTTON

In the first attempt to measure color, in the Division of Cotton Marketing, an investigation was made of various photometric methods and types of apparatus, using both reflected and transmitted light. A photometric method was developed [6] by which an average-reflection measurement might be made of each grade box. A Lummer-Brodhun photometer head was used, and the 12 cartons of the standard box were mounted in the form of a dodecahedron so that an average reading could be made of the whole. This method, however, had numerous disadvantages, since the measurement of brilliance is but a partial measurement of color and since readings for the individual samples are necessary, rather than average measurements for an entire grade box. Figure 3 shows graphically the results of some of these measurements, a box of Middling cotton being taken as a standard.

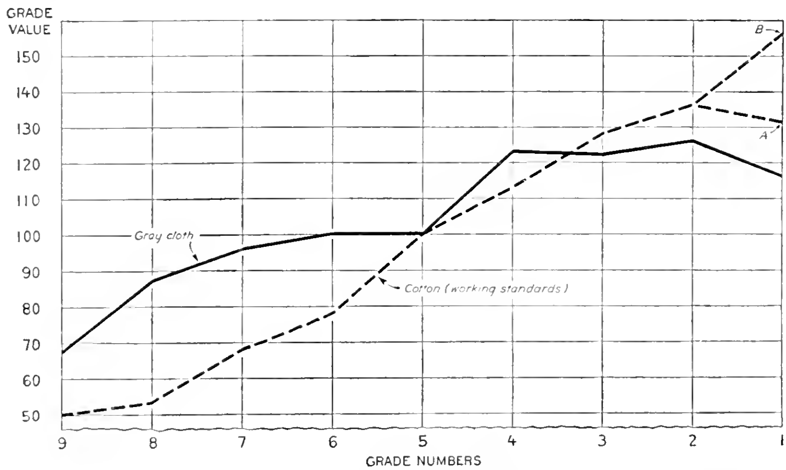

FIGURE 3.—Comparative brilliance of cotton and cloth as determined by photometric readings, with grade No. 5, at 100, used as a basis. (Grade No. 1–A is taken from a box of the working standards, whereas grade No. 1–B is from a special sample of grade No. 1.) Note that the four high grades, Nos. 1 to 4, average about the same in the gray cloth, while Nos. 1 to 3 average about the same for the working standards. This is borne out by the brilliance measurements shown in Figure 12, which indicates that the average brilliance of grades 1 to 4 is approximately the same. (This graph is taken from Dept. Bul. 1488 (*10, p. 27*).)

Later, after making a preliminary study of the situation, it was decided that measurements should be made by several methods before any one method was adopted.

SPECTROPHOTOMETRIC AND PHOTOMETRIC MEASUREMENTS

Two samples each of Middling Fair, Middling, Low Middling, Middling Gray, Good Middling Yellow Stained, Strict Good Middling Yellow Tinged, and Middling Blue Stained cotton were read spectrophotometrically. These same samples with 2 samples each of Good Middling and Strict Middling Yellow Tinged, Strict Middling Gray, and Good Middling Blue Stained, and 10 additional boxes of Middling White, were measured photometrically on the Munsell photometer.

[6] By F. E. Chandler.

Table 1 is given with curves (fig. 4) for the spectrophotometric readings. They were made on a K & E Color Analyzer with a milk-glass standard for which a reflection factor of 0.731 is given. Four readings were taken at wave lengths 30 millimicrons (mμ) apart, from 700 mμ to 430 mμ, and these readings have been averaged and con-

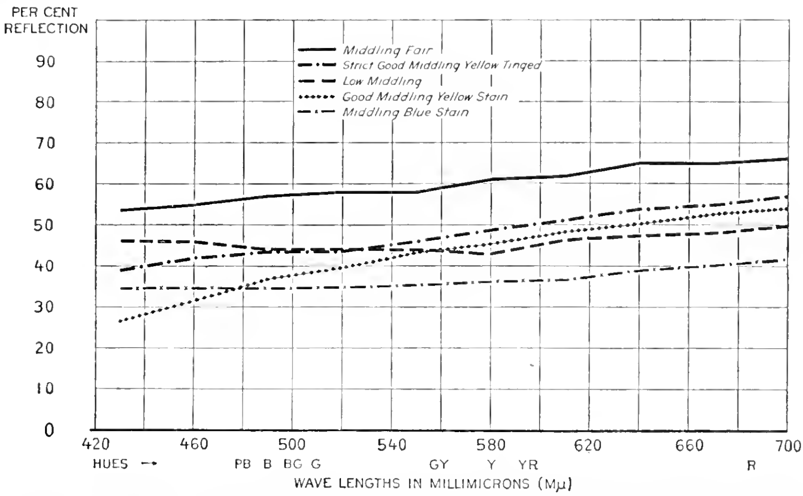

FIGURE 4.—Spectrophotometric curves of five grades of cotton. Readings were made for other grades and for other samples of the same grade. These five readings are sufficient, however, to show how difficult it would be to present graphically 12 variations for each grade from Middling Fair to Low Middling in such a way that each would stand out accurately and definitely

verted by adjusting for the reflection of 0.731 for the milk-glass standard used.

TABLE 1.—*Spectrophotometric measurements of cotton*

Wave lengths (mμ)	Per cent reflection of—													
	Middling Fair		Middling		Low Middling		Middling Gray		Good Middling Yellow Stained		Strict Good Middling Yellow Tinged		Middling Blue Stained	
	No. 1	No. 2	No. 1	No. 2	No. 1	No. 2	No. 1	No. 2	No. 1	No. 2	No. 1	No. 2	No. 1	No. 2
700	66. 1	62. 6	57. 0	65. 4	49. 6	55. 2	------	49. 3	54. 0	45. 3	57. 0	65. 4	41. 7	44. 7
670	64. 9	63. 5	54. 6	63. 6	48. 0	53. 9	------	47. 4	52. 6	45. 2	55. 0	63. 7	40. 1	42. 4
640	65. 1	62. 9	53. 3	60. 7	47. 3	52. 5	------	45. 1	50. 1	42. 1	53. 7	64. 2	38. 9	42. 3
610	61. 8	60. 0	49. 6	59. 2	46. 3	49. 8	------	46. 9	48. 2	40. 0	51. 1	60. 7	36. 6	39. 3
580	61. 0	59. 1	49. 1	57. 7	42. 8	48. 8	------	45. 3	45. 3	36. 2	48. 7	59. 9	36. 2	39. 4
550	57. 9	56. 9	48. 4	57. 7	43. 8	49. 3	------	45. 0	43. 1	34. 9	46. 0	58. 8	35. 4	37. 4
520	57. 9	56. 4	47. 5	58. 1	44. 0	47. 7	------	44. 7	39. 5	32. 5	43. 4	55. 9	34. 7	36. 5
490	56. 9	55. 9	47. 7	57. 7	44. 0	47. 7	------	46. 8	36. 8	30. 8	43. 3	55. 6	34. 4	36. 3
460	54. 8	52. 0	45. 8	57. 9	45. 8	43. 5	------	42. 8	31. 4	29. 9	42. 0	53. 4	34. 5	37. 3
430	53. 4	48. 7	44. 5	56. 7	46. 1	40. 9	------	41. 5	26. 6	28. 1	38. 9	49. 7	34. 4	36. 6

Six readings each were made on the Munsell equality-of-brilliance photometer. The reflection for the milk-glass standard used in the instrument is 0.69. Averages of the six readings, adjusted for 0.69 reflection, are shown in Table 2. Flicker-photometer readings on seven of the samples were made at the same time.

TABLE 2.—*Readings made with an equality-of-brilliance photometer for cotton of different grades*

Grade	Identification No.	Reflection	Identification No.	Reflection
		Per cent		*Per cent*
Middling Fair	1	66	2	66
Middling	1	63	2	63
	3	64	4	64
	5	64	6	63
	7	64	8	64
	9	64	10	65
	11	65	12	60
Low Middling	1	60	2	59
Strict Good Middling Yellow Tinged	1	63	2	65
Good Middling Yellow Tinged	1	62	2	65
Strict Middling Yellow Tinged	1	59	2	59
Good Middling Yellow Stained	1	57	2	59
Good Middling Gray	1	64	2	61
Middling Gray	1	61	2	63
Good Middling Blue Stained	1	59	2	56
Middling Blue Stained	1	52	2	52

All of these readings were measurements of a part or the whole of the color stimulus, yet none seemed such that it could be used for a study of the entire color problem involved in the measurement of cotton. Photometric readings will not do because they are but a partial measurement. Spectrophotometric curves show real differences between grades, but because each sample of cotton is different from the next, with respect to the surface as well as to the color of fiber, because it is impossible to tell what a color looks like from such readings, and because it takes so long to make a careful reading,[7] spectrophotometric curves would not get the student far in studying or even measuring differences within a grade—the lack of precision would be too great. In addition, the surface area of cotton which could be measured in the color analyzer used was limited to a circle one-half inch in diameter. Only measurements over a large area could give results that would be representative of a surface with the variations that are shown by cotton.

COLORIMETRIC MEASUREMENTS

The next step was to measure the color itself, not the stimulus—to measure it in terms of what the eye sees, that is, in terms of hue, brilliance, and chroma.

Regarding the measurement of color, the colorimetry committee (*9*) reported that a 3-dimensional system, employing scales of hue, brilliance, and chroma, might be conceived to be arranged so that neighboring members differ from one another in each of the three attributes by just noticeable differences. The task of working out a theoretically and scientifically perfect system is one that will take time and specialized knowledge to accomplish. Meanwhile, an approach to such a system has been made which works well if one knows in which direction its limitations lie. It is the system worked out by the late A. H. Munsell (*5*) of Boston, examined by Priest and others (*8*). At that time neither science nor art clearly differentiated the three color attributes. Hue and brilliance were rather clearly

[7] To make a thorough spectral analysis of the stimulus of one color, as made at the Bureau of Standards, often requires an entire day.

defined, but chroma, or color intensity, remained vague and elusive. For purposes of illustration Munsell constructed a sphere by which to illustrate his idea that accurate scales of color could be made in any one attribute only when the other two attributes were held constant.

The vertical axis of the sphere illustrates an 11-step scale of brilliance from 0 to 10, black to white, each step equally distinguishable from the next. Hue varies about the circumference of the sphere in spectrum order, purple and red-purple connecting the red and purple-blue ends of the visible spectrum. Instead of having all the colors at full intensity on the surface of the sphere, the chroma scales are stepped off from 0, at the neutral center of the sphere, by five equidistant steps to the surface. In the blue and blue-green, five chroma

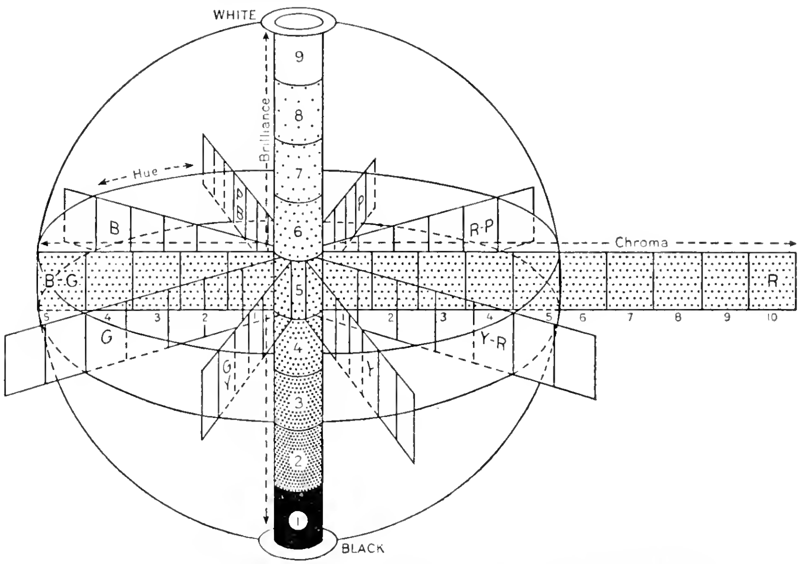

FIGURE 5.—The 3-dimensional relationship of color—color described by three attributes: Hue, brilliance, and chroma

steps make a maximally strong color, but in the red and yellow the fifth chroma step is not a maximum color. Accordingly, the sphere was enlarged to the form of a so-called color tree, the skeleton of a color solid, in which the branches could grow out as far as there are chroma steps to illustrate them. (Fig. 5.) In order that this concept of color might be useful, color charts were made that would illustrate it. The colors are made of permanent pigments carefully specified and measured so that the scales in any one direction approximate closely a series of equally perceptible hue, brilliance, and chroma steps.[8]

EXPLANATION OF COLOR NOTATION

The notation which has been built up around this color solid is, for the practical worker, as important as the 3-dimensional idea of color. (Fig. 6.). Five hues—red, yellow, green, blue, and purple—form the

[8] ATLAS OF THE MUNSELL COLOR SYSTEM, Baltimore, Md.

basis for the hue circle. Midway between them are the intermediate hues, yellow-red, green-yellow, blue-green, purple-blue, and red-purple, making a series of 10 hues, each equidistant to the eye from the next. The first letter of the name is used for the hue notation except when

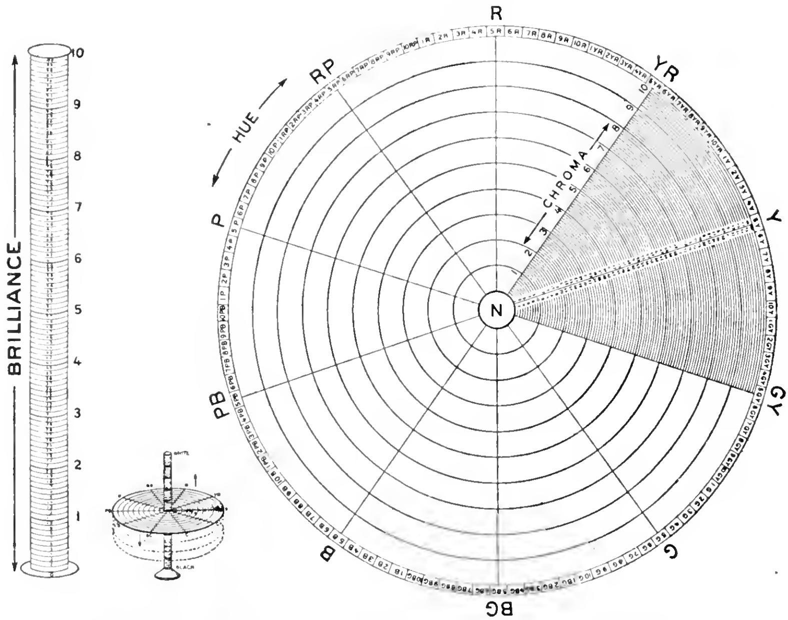

FIGURE 6.—Color notation in terms of both 10 and 100 steps each of hue, brilliance, and chroma

many more than 10 hues are to be used. Then a numerical notation may be substituted. The notation for a part of the hue circle is illustrated in Figure 7. Note that the standard red may be used as R, 5R, or 5, depending entirely upon the way in which one wishes to use it. When used without a hue letter the hue figure must be separated from those denoting brilliance and chroma. Subdivisions for

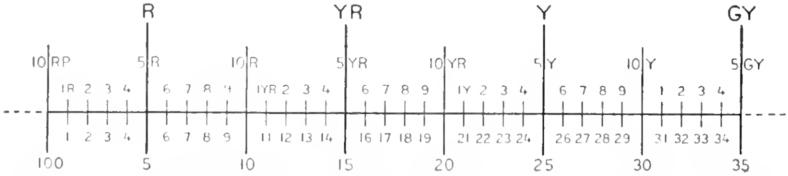

FIGURE 7.—Hue notation through a portion of the hue circuit, illustrating the numerical notation and that in which the letters of the hue names are employed

hue as fine as the eye can detect are made possible by the use of the decimal system.

The brilliance scale begins at 0, which is absolute black, and progresses through equal steps to a middle gray at 5, and from there to absolute white at 10. These steps may also be subdivided decimally to a degree as small as the eye can determine.

The notation for chroma begins at neutral gray, which is 0, and progresses through equal steps to as strong a color as is required. The end points vary for each brilliance and hue, with colors represented by pigments like vermillion and ultramarine extending as far as 10 in chroma. A weak color will have the notation of 1, 2, or 3, while strong colors may go out to 8, 9, 10, or even farther. Decimals may again be used for expressing finer differences.

The complete notation is always written in the following order: Hue, brilliance, chroma. For example, red, 4 in brilliance, and 10 in chroma is written as 5R 4/10. If the hue letter is omitted, the notation may be written as 5–4/10.

Colors of standard notation made from permanent pigments may be procured from commercial manufacturers or, if time and equipment are available, any colors may be standardized according to this notation and may be used for further work.

By the use of Maxwell disks (disks cut with a radial slit so that several may be slipped together with portions of each visible) and a motor on which to spin them at a speed great enough so that there is no flicker, any color which lies in the color solid within the region bounded by the colors used may be matched.

For cotton work it was found that Y 8/9, YR 6/8, N 9.4/, and N 7/, with the addition of N 6/ in a few of the lower grades, would measure the white grades.

It can be seen from Table 3 that the readings made on different days show considerable variation, but that the readings for both brilliance and chroma on the white cottons indicate a distinct trend, the lower grades becoming darker in brilliance and weaker in chroma. The spots, tinges, and stains become progressively stronger in chroma, whereas the extra whites, grays, and blues become weaker in chroma. The yellow stains are reddest in hue, whereas the so-called blue stains are yellow, sometimes slightly greenish yellow. In every case the average measurements on the cotton samples correspond with the "way they looked." It seems hardly necessary to state this fact if it is remembered that what is being measured is what they look like, and not the composition of the stimulus factors.

By a comparison of the results obtained from the methods experimented with—photometric, spectrophotometric, and colorimetric [9]—it seemed simplest and most satisfactory to adopt this last-described method in the color studies to be made regarding cotton, using disks of Munsell notation, with modifications in set-up that would permit more precise readings.

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[9] There are many colorimetric methods besides that which uses Maxwell disks—among them the Hess-Ives tintometer and the Eastman colorimeter. In all of them colors are matched, some by an additive and some by a subtractive effect, some matches being made through successive selective filters, some by varying proportions of standard wedges. Color matches may also be made by use of Lovibond glasses, which the Bureau of Standards will check in terms of their standard set of these glasses.

TABLE 3.—*Preliminary color readings on specified grades of cotton in terms of hue, brilliance, and chroma, made under a north skylight in June, 1927* [1]

Grade	Sample No.	Weather	Percentage of specified standard color disks used				Color notation		
			YR 6/8	Y 8/9	N 9.4/	N 7/	Hue-Brilliance/chroma		
Middling fair	1	Cloudy	4	22	58	16	4.0Y	8.75/	2.32
		Gray	4	21.5	65	10.5	3.9Y	8.79/	2.25
		Bright	2	25.5	59	12.5	4.5Y	8.68/	2.45
Good middling	1	Cloudy	5.5	23.5	53.5	17.5	3.6Y	8.54/	2.55
		Gray	5.5	22.5	52	20	3.6Y	8.49/	2.47
		Bright	1.5	26.5	56.5	15.5	4.6Y	8.66/	2.60
	2	Cloudy	6.5	22	60.5	11	3.4Y	8.68/	2.50
		Gray	5	24	50	21	3.8Y	8.47/	2.56
		Bright	2	26.5	58	13.5	4.5Y	8.69/	2.54
Middling	1	Cloudy	7	16.5	34.5	32	2.8Y	7.70/	2.05
		Gray	3	18.5	43	35.5	4.0Y	8.27/	1.91
		Bright	3	21.5	53.5	22	4.1Y	8.54/	2.17
	2	Cloudy	5	18	35.5	31.5	3.8Y	7.75/	2.02
		Gray	3	19	40	38	4.0Y	8.20/	1.95
		Bright	2.5	19.5	60.5	17.5	4.2Y	8.68/	1.95
		Bright	2	20	55	23	4.4Y	8.57/	1.96
Low middling	1	Cloudy	3	14	24	59	3.8Y	7.77/	1.50
		Gray	2	16	20	62	4.2Y	7.68/	1.60
		Bright	1	18.5	32	48	4.6Y	8.00/	1.74
	2	Cloudy	3.5	14	16.5	66	3.6Y	7.56/	1.54
		Gray	3	16	26	55	3.8Y	7.83/	1.68
		Bright	1.5	18.5	38.5	41.5	4.3Y	8.17/	1.78
Good Ordinary	1	Cloudy	3.3	14	16	66.7	3.7Y	7.55/	1.52
		Gray	2.5	13.5	14	70	3.9Y	7.50/	1.42
		Bright	1	18	23	58	4.6Y	7.79/	1.70
	2	Cloudy	3	12.5	6.5	78	3.6Y	7.28/	1.36
		Gray	2.5	14.5	8.5	74.5	4.0Y	7.36/	1.51
		Bright	1.5	13.5	16.5	68.5	4.3Y	7.57/	1.30
Good Middling Spotted	1	Raining	4.5	24.5	36	35	3.9Y	8.14/	2.56
		Bright	4	30	51	15	4.2Y	8.43/	3.02
		Bright	1	30	59	10	4.2Y	8.73/	2.78
		Bright	5	28	56	11	3.9Y	8.64/	2.92
	2	Raining	5	24.5	40.5	30	3.7Y	8.18/	2.60
		Bright	2	28	51	19	4.5Y	8.54/	2.68
		Bright	------	31	55	14	5.0Y	8.67/	2.79
		Bright	2.5	32.5	55.5	9.5	4.5Y	8.70/	3.13
Strict Low Middling Spotted	1	Raining	5	21	28	46	3.7Y	7.91/	2.29
		Bright	2	23	34.5	40.5	4.4Y	8.10/	2.23
		Bright	1.5	25.5	37	36	4.6Y	8.19/	2.42
		Bright	5	23	46	26	3.8Y	8.36/	2.47

[1] This table demonstrates the extent of precision that can be expected under the best of natural daylight conditions. See Table 8 and compare standard deviations with Table 5.

MATCHING OF COLOR

The simplest method of color matching is to spin the color disks in juxtaposition to the sample, using a neutral mask with openings of equal size, one over the disks, the other over the sample (fig. 8), and to compare by eye the two fields.

A preliminary test was made by this method on a number of cottons, part of them listed in Table 3. The light used was that which comes through the north skylight in the cotton-grading room of the Division of Cotton Marketing, the glass being set at an angle of 20°. The cotton and the disks, with mask covering, are shown in Figure 8 as they were set up for this experiment. Three independent measurements were repeated on the same samples on following days.

The readings are made in percentages of the disks used to match each sample, and these readings are converted by formulas (to be described later) into terms of hue, brilliance, and chroma.

DEVELOPMENT OF APPARATUS

In order to make measurements in terms of hue, brilliance, and chroma, it is necessary to work out a convenient method for setting up the material always in the same way, for lighting it at a constant angle, for making the observations always from a single point, and for getting two similar fields for comparison. For the cotton work, a holder was built into which a single small sample carton might be slipped, the surface of the cotton to be as nearly as possible in the same plane with the disks used as standards, both at an angle of approximately 38° from the horizontal. A comparator eyepiece was developed [10] on specification which required that two fields approximately 2 3/16 inches in diameter, separated by a small space, perhaps half an inch, should be brought into a single comparison field within an eyepiece. Only one-half of each of these fields is visible in the eye-

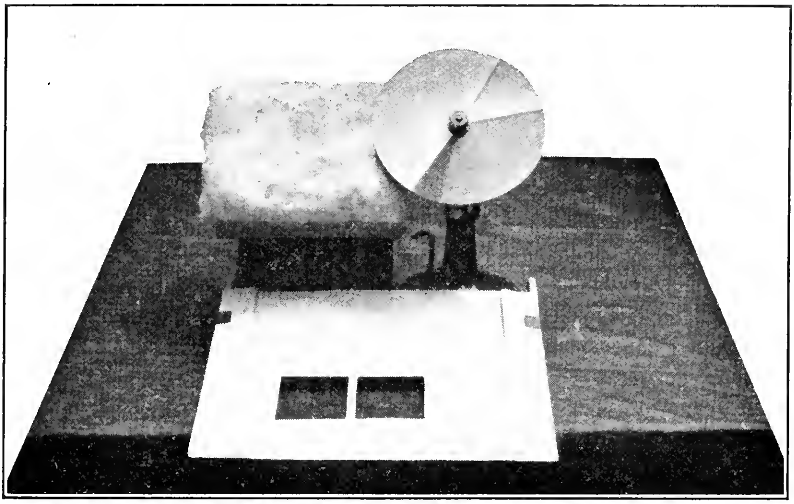

FIGURE 8.—Simple method of color matching. Color disks are spun in juxtaposition to the sample being measured, with a neutral mask in which openings of equal size are so cut that one may be placed over the disks, the other over the sample. The two fields are compared by eye

piece. The use of lenses and a prism puts the cotton surface sufficiently out of focus so that the result appears as one solid color, even though the cotton itself might have a very spotty appearance.

With this set-up Macbeth artificial-daylight lamps were used, measured for color temperature by the Bureau of Standards. Their report on these lamps read in part as follows:

The incandescent lamps received with the daylight units were 200 watt, 110 volt, pear-shaped, frosted tip, gas filled lamps.

The daylight units—incandescent lamp, reflector, and daylight glass—were tested as received, the color temperature of the unit as a whole being determined in each case. The incandescent lamps were operated at 110.0 volts. Measurements were made at a distance of about 40 cm from the daylight glass and approximately along the axis of the light beam.

Values of color temperature were determined on the rotatory dispersion colorimetric photometer described in the J. O. S. A. & R. S. I., v. 7, p. 1175–1209; December, 1923. Two observers (D. B. J. and K. S. G.) made measurements with closely agreeing results. The average is reported. The following values of color temperature were thus obtained:

Lamp	*Color Temperature.*
A	7560° K
B	8100° K

[10] By Bausch & Lomb Optical Co.

The color match with the black body color was in both cases good (*4*, *7*).

Daylight lamps were used in order that the best conditions under which cotton classers work might be duplicated. Their preference is light from a north sky, and the lamps used were selected after consultation with experienced classers who took samples of cotton and classed them under filters which gave a variety of color temperatures.

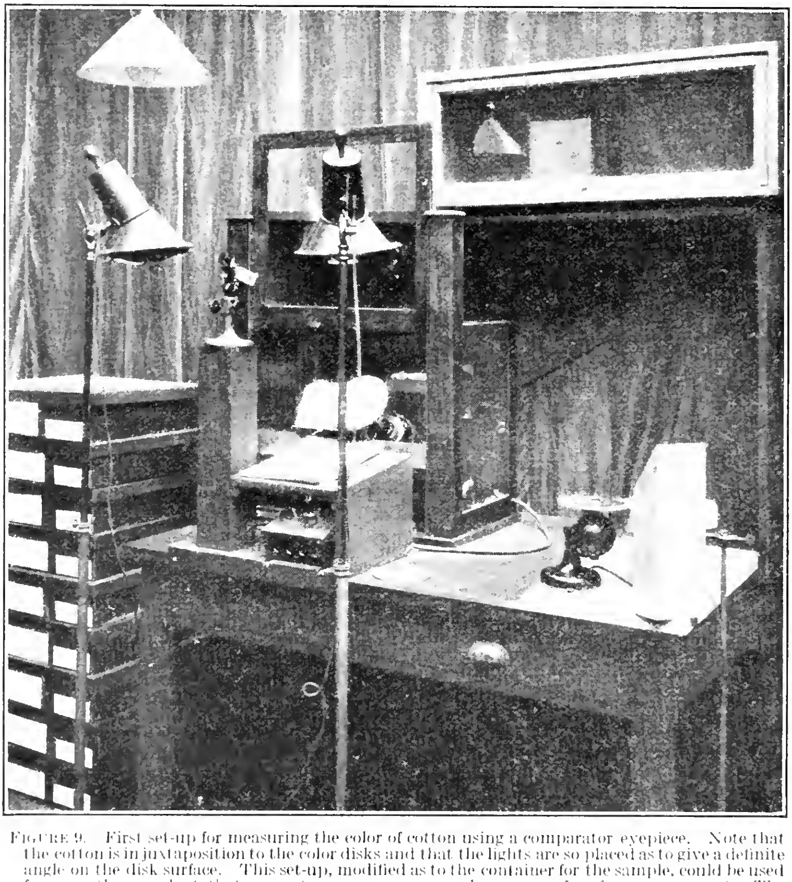

FIGURE 9. First set-up for measuring the color of cotton using a comparator eyepiece. Note that the cotton is in juxtaposition to the color disks and that the lights are so placed as to give a definite angle on the disk surface. This set-up, modified as to the container for the sample, could be used for any other product that presents an even or a nearly even surface for measurement. The equipment has already been used for measuring the color of bread, cheese, condensed milk, and cotton cloth

The lamps were marked so that they could always be set up in the same position, at the same angle, the light to fall on the samples at approximately 45°, possibly a little less. Figure 9 shows the entire equipment.

The colors chosen for standards are the four which, in combination, will match all but the very lowest grades of white cotton. They are Y 8/9, YR 6/8, N 9.4/, and N 7/. For a very few matches a slightly darker gray is necessary, and sometimes a green-yellow. These six colors were sent to the Bureau of Standards for measurement of spectral reflectance (Table 4), in order, as the report reads, to put on record data which are suitable and adequate to specify these colors, so that the reproduction of these present standards at some future time may be verified without depending upon the permanence of the color of these particular specimens.

For duplication of these data at any future time it is necessary that the samples be viewed normally under completely diffuse illumination; that is, under conditions identical with those of the original test. In this way a measurement is obtained which completely specifies the stimulus for these colors.

With this equipment, set up in a dark room, lighted only by artificial daylight, measurements were made on a series of 10 sets of practical forms of the standards, from No. 2, Strict Good Middling to No. 9, Good Ordinary. One box of No. 1, Middling Fair was measured.

TABLE 4.—*Spectrophotometric measurements on the six Munsell papers which are used in cotton measurements and which were submitted to the Bureau of Standards for testing* [1]

Wave length in millimicrons	YR 6/8	Y 8/9	GY 6/8	N 6/	N 7/ (37–N)	N 9.4/ (57–N)
380	0.0603	0.0563	0.0700	[2] 0.375	[2] 0.433	[2] 0.70
390	.0609	.0582	.0911	[2] .375	[2] .433	[2] .73
400	.0616	.0598	.0959	.375	.433	.755
410	.0626	.0612	.0981	.375	.433	.773
420	.0638	.0625	.0995	.375	.433	.787
430	.0655	.0640	.101	.375	.433	.799
440	.0683	.0662	.102	.375	.433	.811
450	.0728	.0719	.105	.375	.433	.821
460	.0790	.0832	.111	.375	.433	.829
470	.0879	.110	.121	.375	.433	.837
480	.100	.151	.137	.375	.433	.843
490	.113	.212	.168	.375	.433	.848
500	.128	.298	.225	.375	.433	.851
510	.148	.385	.306	.375	.433	.853
520	.172	.455	.408	.375	.433	.854
530	.201	.514	.502	.375	.433	.855
540	.243	.562	.541	.375	.433	.855
550	.297	.603	.535	.375	.433	.855
560	.361	.635	.504	.375	.433	.855
570	.430	.660	.465	.375	.433	.855
580	.494	.678	.427	.375	.433	.855
590	.554	.692	.398	.375	.433	.855
600	.609	.701	.370	.375	.433	.855
610	.650	.709	.346	.375	.433	.855
620	.679	.714	.325	.375	.433	.855
630	.698	.718	.308	.375	.433	.855
640	.710	.723	.294	.375	.432	.855
650	.721	.726	.283	.375	.431	.855
660	.730	.730	.274	.375	.430	.855
670	.737	.735	.266	.375	.429	.855
680	.745	.739	.261	.375	.428	.855
690	.753	.744	.257	.375	.427	.855
700	.760	.748	.254	.375	.425	.855
710	.766	.752	.251	.375	.422	.855
720	.773	.756	.249	.375	.418	.855

[1] $\frac{\text{Brightness of sample}}{\text{Brightness of MgO}} = Bx/Bo$, for completely diffused illumination and line of sight perpendicular to surfaces of sample and standard.

[2] Estimated. If zinc oxide (ZnO) is a principal constituent of these pigments, these estimated values will be greatly in error.

METHOD OF MEASUREMENT

The measurement is made by changing the areas of the disks until there is a match when viewed through the eyepiece. Since the lenses and prism of the color comparator are interposed between the eye and the sample, the color area is rid of all detail and presents a uniform field for measurement. It is easy, therefore, after short training for anyone with normal color vision [11] to make a color

[11] Qualitative tests for color vision—extremely important in all colorimetric work—may be made by the use of either or both of the following sets of charts: ISHIHARA, TESTS FOR COLOR BLINDNESS, and STILLING'S PSEUDO-ISOCHROMATIC PLATES FOR TESTING COLOR SENSE.

match. If a color measurement on a single sample is desired, several measurements should be made and an average taken, just as would be done in any other method of colorimetric or spectrophotometric measurement.

In making the readings on cotton an average was more important than readings on individual samples. For that reason only two read-

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Date April 4, 1928
Place Washington, D.C.
#5 – Mid. Set 6

Position in Grade Box	Observer		YR 6/8 Notation	YR 6/8 % Area	Y 8/9 Notation	Y 8/9 % Area	N 9.4/ Notation	N 9.4/ % Area	N 7/ Notation	N 7/ % Area	Hue	Brilliance	Chroma	Notation
1				2.5 2.5		20.5 20.5		43 43.		34 34				
2				2.5 3.		18.5 20.		44.5 50.5		34.5 26.5				
3				3. 3.		20. 21.		53. 52.		24. 24.				
4				3.5 3.5		23.5 25		48.5 50.5		24.5 20.5				
5				3.5 3.5		20.5 20.5		51. 49.		25. 27.				
6				3.5 3.5		23.5 23.5		46 46.		27. 27.				
7				3.5 3.5		20. 19		52.5 51.5		24 26				
8				3. 3		19.5 18		48.5 46		29 33				
9				3.5 3.5		20.5 20.5		43.5 51.		32.5 25				
10				3.5 3.5		19.5 19.5		53. 53.		24 24				
11				3.5 3.5		17. 17.5		48.5 49		31 30				
12				3.5 3.5		22.5 22.5		45. 45.		29 29				

Symbols: A = Area B = Brilliance
H = Hue C = Chroma
P = Power = $B \times C$

Notation: $H\ {}^{B}/_{C}$ X = Number of 1st hue, clockwise
Z = Number of 2nd hue, clockwise

Formulas: Hue: $Z - \frac{A_X P_X}{A_X P_X + A_Z P_Z}(Z-X)$

Brilliance: $\sqrt{\frac{A_1B_1^2 + A_2B_2^2 + \cdots}{100}}$

Chroma: $\frac{A_1C_1 + A_2C_2 + A_3C_3 + \cdots}{100}$

FIGURE 10.—Record sheet used when making color measurements

ings were made on each of the samples, one on each side of the individual cartons. Thus, two areas were measured, each one-half of $2\frac{3}{16}$-inch-diameter circles. The two readings were averaged for each sample.

The readings are recorded by noting the percentage of the exposed area of each color. A calibrated disk (in terms of per cent) is used for this purpose. Figure 10 shows the form record sheet with readings made on Middling White cotton. This reading goes as far as most colorimetric methods do. It provides a record in terms of percentage of the area of each of the several standards used to make a match. For instance, an average color for Middling cotton may be established, the disks set up in the required areas, and samples of cotton set in, those that match being accepted as Middling, those that do not match being rejected. Yet this is but a part of the problem, for it is not enough to give an arbitrary match; the problem is to study the color relations within grades and between grades, possible only when the measurement is put on record in terms of hue, brilliance, and chroma, the three attributes by which color is described as it is seen.

FORMULAS FOR COLOR NOTATION

For converting the percentage area of standard colors into terms of hue, brilliance, and chroma, the Munsell system of notation is used. The following formulas, although used approximately at previous times, first became a matter of record when they were made a part of the record sheet of the Bureau of Agricultural Economics. There are one or two precautions that must be observed in using these formulas: (1) The hues selected should not be more than one-tenth of the hue circle apart; (2) the low brilliance steps, 1/ and 2/, should not be used if it is possible to use lighter colors; and (3) a single set of four disks should be used throughout any one piece of work wherever it is practicable to do so. The formulas will give satisfactory relative results just as long as a single set of colors is used. For instance, all cotton readings will be in relation, one to the others, as long as YR 6/8, Y 8/9, N 9.4/, and N 7/ are used. But should N 1/ be used instead of N 7/, it would still be possible to match the cotton; but since the square of brilliance is used in the formula, a slight error in the notation of the original color would be proportionally of more consequence in squaring 1 and 2 than in squaring 6 or 7.[12]

HUE

The hue notation is simply the proportion of one hue to the total. Instead, however, of using only the area proportion, the area is multiplied by its brilliance and its chroma, to give what may be called

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[12] Since this bulletin was written, a new Book of Color has been published by the Munsell Color Co. It contains a set of charts revised and enlarged to give scales that are more consistent with the psychological data now available. The brilliance scale is corrected, and 20 hues, instead of 10, are included. Data regarding the brilliance scale may be found on page 42 of the new publication. It is hoped that data on the hue and chroma scales will be published. Since these new papers depart somewhat from the old, it is more important than ever in following the formulas given above to use a single set of colors throughout any one study so that the results may be in the proper relation. This does not mean the same disks, but disks of the same notation.

Ordinarily, a single investigator is interested chiefly in the results of his own problem, yet he may sometimes wish to convert the readings made of many different sets of colors into a relation that will hold more rigorously than the relative results to be obtained by the formulas described above. It is therefore suggested that the colorimetry committee report previously cited (*9*) provides, on pages 579 to 592, a method for reducing diverse color specifications to the common denominator apparently provided by the *elementary color excitations*.

the "power"[13] number of the color. The following formula is quite simple:

$$H = z - \frac{A_x P_x}{A_x P_x + A_z P_z}(z - x)$$

in which

x = number of first hue (clockwise on the hue circle). (Fig. 7.)
z = number of second hue (clockwise on the hue circle). (Fig. 7.)
A = area.
P = power number (brilliance × chroma).
H = hue resultant.

Working out the first reading on Figure 10 gives 2.5% of YR 6/8 and 20.5% of Y 8/9. The other two colors are neutrals; they have no hue and are therefore 0 (and thus disregarded) in the formula given. Since z, the second hue, is Y, it has a hue notation, in figures, of 25 (see fig. 7 for hue notation) while x, which is YR, is 15. The area of the first hue, A_x, is 2.5, and P_x, the power number of the first hue, is 6 × 8, that is, its brilliance times its chroma. A_z, the area of the second hue, is 20.5, and P_z, the power number of the second hue, is 8 × 9, its brilliance times its chroma. Substituting in the formula gives

$$H = 25 - \frac{2.5(6 \times 8)}{[2.5(6 \times 8)] + [20.5\,(8 \times 9)]}(25 - 15)$$

$$H = 25 - \frac{120}{1596}(10)$$

$$H = 25 - .75$$

$$H = 24.25$$

Translated into terms of Y by reference to Figure 7, this is 4.25Y, or, dropping the last figure, 4.2 or 4.3Y, the hue of the cotton matched.

More than one card of the same hue may be used, as in the yellow of the following match for alfalfa hay:

$$25 \text{ per cent YR } 4/5 + \begin{cases} 49 \text{ per cent Y } 3/3 \\ 26 \text{ per cent Y } 4/4 \end{cases}$$

The power (P) of each is multiplied by its respective area and added together to give a total for its hue, as follows:

$$H = 25 - \frac{25(4 \times 5)}{[25(4 \times 5)] + [49(3 \times 3) + 26(4 \times 4)]}(25 - 15)$$

$$H = 25 - \frac{500}{500 + 441 + 416}(10)$$

$$H = 25 - 3.68$$

$$H = 21.32, \text{ or } 1.32\text{Y}$$

[13] This term is perhaps more easily understood by reference to colors used in outdoor advertising: To be effective at any distance the power of the color must be great. A dark blue, although it might be quite strong (PB 1/10) can not compete with a brilliant yellow (Y 8/9) or a brilliant orange (YR 6/10). The power of the PB given in this example is but 10, while that of the Y is 72, and the YR, 60. As the blue is increased in brilliance or chroma, perhaps to PB 5/12, it begins to compete with the yellow and orange.

By referring to Table 6, it will be seen that the conversion in terms of per cent natural green color in alfalfa hay is 10.

The same thing may be done with more than two areas of a single hue, as in the following match for a greener sample of alfalfa hay:

$$17 \text{ per cent YR } 5/4 + \begin{cases} 32 \text{ per cent Y } 5/5 \\ 11 \text{ per cent Y } 5/4 \\ 40 \text{ per cent Y } 4/4 \end{cases}$$

$$H = 25 - \frac{17(5\times4)}{[17(5\times4)] + [32(5\times5) + 11(5\times4) + 40(4\times4)]}(25-15)$$

$$H = 25 - \frac{340}{340+1660}(10)$$

$$H = 25 - 1.7 = 23.30, \text{ or } 3.30 \text{ Y}$$

The conversion in terms of "per cent natural green" alfalfa is 26.

BRILLIANCE

In working out the brilliance of any match, the area of each color is multiplied by the square of the brilliance. The square of brilliance is used since reflection under certain illuminations bears a relation to brilliance according to a square law. For instance, half black and half white mixed by means of disks do not produce a gray that looks half way between black and white.[14] Instead, the color looks nearer to three-quarters of the way towards white. When about one-quarter white and three-quarters black are mixed on disks, the result is very near to a middle gray. That means that 25 per cent white with 75 per cent black is approximately 5/ in brilliance, while 50 per cent white and 50 per cent black is nearer 7/ in brilliance. Brilliance scales made up of painted papers of equally perceptible steps will vary with illumination, and up to the present time no definite scale has been adopted. The Munsell scale was made to follow the square law (practical because a cat's-eye shutter is used in the Munsell photometer), but since the white used in the original photometer as a standard was not calibrated on the basis of total reflection, but was used as 10/, the highest brilliance step, the scale does not exactly follow this law. However, it closely approximates it, and will give readings that are relatively correct. Further work regarding this relationship has been done both by I. G. Priest, at the United States Bureau of Standards, and by the Munsell Research Laboratory.

The formula that is used is as follows:

$$B = \sqrt{\frac{A_1 B_1^2 + A_2 B_2^2 + A_3 B_3^2 + \cdots\cdots}{100}}$$

when B = brilliance and the area is expressed in percentage. Working out the first reading on Figure 10, gives 2.5 per cent YR 6/8, 20.5 per cent Y 8/9, 43 per cent N 9.4/, and 34 per cent N7/—the square root of the sum of the different brilliance readings squared and multiplied

[14] This is in general accordance with the Weber law which states that the just appreciable increase of stimulus bears a constant ratio to the original stimulus. See Priest's discussion (8, p. 20-31).

by their respective areas, and the whole divided by 100, the total per cent area. In other words

$$B=\sqrt{\frac{(2.5\times 6^2)+(20.5\times 8^2)+(43\times 9.4^2)+(34\times 7^2)}{100}}$$

$$B=\sqrt{\frac{6867}{100}}=\sqrt{68.67}=8.29$$

The brilliance of this color match is 8.29.

CHROMA

The chroma of any color match is the proportion of the chromas used to the total, or 100 per cent of the area. The formula is simply the sum of the per cent area of each color multiplied by its chroma, as follows:

$$C=\frac{A_1C_1+A_2C_2+A_3C_3+\cdot\ \cdot\ \cdot\ \cdot}{100}$$

when C = chroma.

Working out the first reading of Figure 10 for chroma gives

$$C=\frac{(2.5\times 8)+(20.5\times 9)}{100}=2.05$$

It makes no difference whether two or many more colors are used, the formula remains the same so long as the colors are not more than one-tenth of the hue circle apart. For instance, solving the alfalfa reading gives 17 per cent YR 5/4, 32 per cent Y 5/5, 11 per cent Y 5/4, 40 per cent Y 4/4; substituting in the formula gives

$$C=\frac{(17\times 4)+(32\times 5)+(11\times 4)+(40\times 4)}{100}=4.32$$

INTERPRETATION OF COLOR MEASUREMENTS

It is highly important that careful analysis be made of the results of the color readings. For that reason the readings made in the cotton problem are analyzed and discussed in the following paragraphs, with statement as to what they may mean in terms of cotton.

The measurement of the first reading made on cotton in Figure 10 is, according to the solution presented, 4.3Y 8.29/2.05. Table 5 gives the measurement for the other readings in terms of hue, brilliance, and chroma. Those hues which are 4.3 and 4.4 are slightly more yellow in hue than 4.2, while 3.9 and 4.0 are slightly more reddish than 4.2. The highest brilliance readings indicate the brighter, lighter cottons; highest chroma readings indicate the creamiest of the cottons; the low chromas indicate the so-called "bluish" cottons.

It is interesting to discover that the term "blue," as applied to cotton, does not indicate a real difference in hue; it indicates lack of chroma in comparison with the creamy bales. According to the law of simultaneous contrast, each color affects every color with which it comes in contact. The slighter the differences are, the greater the relative differences appear. Black and white, for instance, offer the maximum of brilliance contrast for reflecting surfaces. Therefore any simultaneous contrast does not seem to affect these differences as much as it does two grays that are almost alike. Hold the grays apart and you may be unable to tell which is which; yet once they are put together the difference is magnified by simultaneous contrast; the lighter gray of the two appears still lighter, whereas the darker gray looks darker. For example, which of the grays in Figure 11 looks lighter? They are actually alike; yet the gray which is placed against the dark background looks much lighter than the gray against the white background.

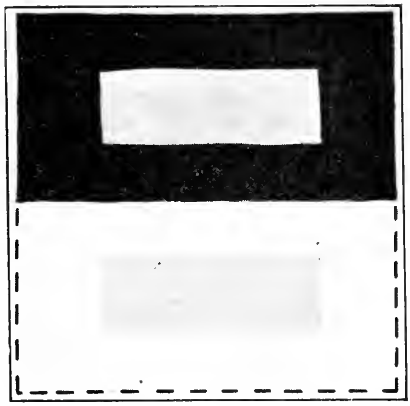

FIGURE 11.—Illustration of contrast as applied to light and dark areas. Chromatic areas present similar problems in contrast. The central rectangle surrounded by dark looks considerably lighter than the central rectangle surrounded by light; yet they are actually the same. Questions of contrast enter into many color problems

The averages of the measurements made on 10 sets of the practical forms of the cotton standards are given in Table 5, with standard deviations (σ) for brilliance and chroma which show the variations about the average. (Refer to Table 3; note descriptive title.) Hue varies so very little—only

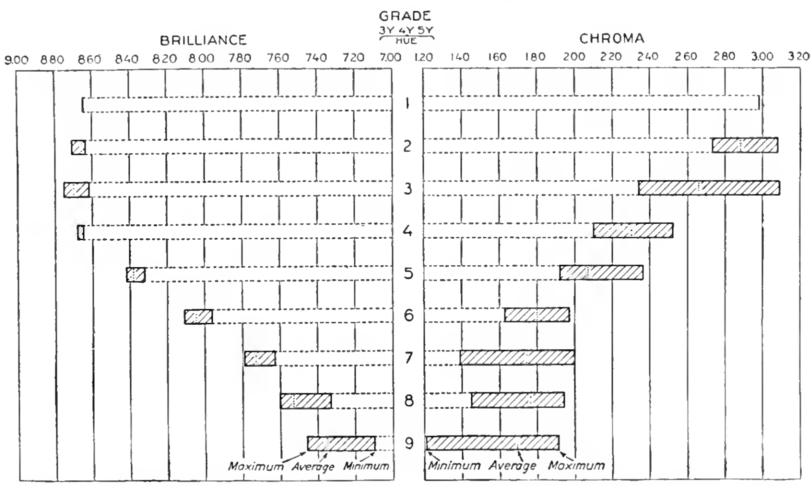

FIGURE 12.—Average of the grade and extremes for 10 sets of the practical forms of white cotton that have been measured for hue, brilliance, and chroma. The brilliance average for the four highest grades is nearly constant. Not very much tolerance from the high to low samples is represented in the grade box. From No. 4, Strict Middling, each grade becomes considerably darker, with a greater tolerance as between the lightest and darkest samples in the grade. Chroma measurements for the nine grades show considerable tolerance within each grade. The averages, however, progress gradually from the high grades in which the cottons are of a creamy color to a grayer cotton in the lower grades. From grade No. 6 to grade No. 9 thea verages for chroma are nearly constant

between 3 Y and 5 Y—that no standard deviation has been worked out for it. Brilliance and chroma measurements are charted in Figure 12.

TABLE 5.—*Average of color readings on 10 sets of practical forms of the standards in terms of hue/brilliance/chroma with standard deviations* (σ) *for brilliance and chroma*

Grade	Position 1	σ	Position 2	σ	Position 3	σ	Position 4	σ	Position 5	σ	Position 6	σ
1. Middling Fair	40Y 8.60/2.91		39Y 8.61/3.03		39Y 8.61/3.08		38Y 8.68/3.09		37Y 8.66/3.00		37Y 8.64/2.85	
2. Strict Good Middling	41Y 8.67/2.78	0.09/0.10	41Y 8.69/2.89	0.07/0.14	41Y 8.71/2.87	0.10/0.11	42Y 8.65/3.08	0.09/0.07	41Y 8.65/2.97	0.10/0.11	41Y 8.68/2.80	0.07/0.10
3. Good Middling	41Y 8.77/2.43	.10/ .19	42Y 8.68/2.79	.08/ .15	42Y 8.69/2.78	.08/ .09	42Y 8.65/3.09	.05/ .10	42Y 8.66/2.75	.06/ .08	42Y 8.77/2.42	.09/ .16
4. Strict Middling	41Y 8.65/2.12	.09/ .16	41Y 8.65/2.19	.09/ .09	42Y 8.66/2.28	.08/ .10	42Y 8.69/2.69	.09/ .17	42Y 8.68/2.41	.07/ .18	41Y 8.68/2.16	.05/ .13
5. Middling	41Y 8.35/2.15	.10/ .10	41Y 8.38/1.99	.11/ .08	40Y 8.41/2.01	.12/ .12	42Y 8.38/2.36	.09/ .08	41Y 8.36/2.02	.11/ .12	41Y 8.35/2.16	.13/ .13
6. Strict Low Middling	41Y 8.08/1.75	.13/ .09	41Y 8.11/1.72	.09/ .07	41Y 8.06/1.94	.12/ .13	41Y 8.06/1.97	.07/ .12	41Y 8.10/1.87	.11/ .06	40Y 8.07/1.73	.08/ .09
7. Low Middling	41Y 7.78/1.77	.17/ .12	40Y 7.74/1.65	.13/ .10	41Y 7.79/1.76	.08/ .14	41Y 7.75/2.00	.08/ .06	39Y 7.75/1.78	.08/ .08	41Y 7.74/1.75	.11/ .12
8. Strict Good Ordinary	41Y 7.60/1.79	.09/ .10	41Y 7.60/1.73	.08/ .10	41Y 7.60/1.83	.09/ .07	41Y 7.57/1.94	.09/ .09	41Y 7.57/1.78	.12/ .08	41Y 7.56/1.79	.09/ .07
9. Good Ordinary	41Y 7.36/1.65	.08/ .05	41Y 7.35/1.67	.08/ .08	42Y 7.41/1.85	.07/ .09	42Y 7.32/1.84	.09/ .13	41Y 7.46/1.84	.06/ .06	41Y 7.39/1.69	.05/ .07

Grade	Position 7	σ	Position 8	σ	Position 9	σ	Position 10	σ	Position 11	σ	Position 12	σ
1. Middling Fair	38Y 8.67/3.00		40Y 8.67/2.90		39Y 8.60/2.92		41Y 8.62/3.09		40Y 8.76/2.84		38Y 8.59/3.08	
2. Strict Good Middling	41Y 8.68/2.87	0.11/0.13	41Y 8.65/2.74	0.07/0.16	42Y 8.65/2.85	0.07/0.66	42Y 8.68/2.98	0.08/0.09	42Y 8.64/2.73	0.06/6.16	43Y 8.66/3.65	0.66/0.13
3. Good Middling	42Y 8.71/2.75	.08/ .15	42Y 8.78/2.38	.07/ .11	42Y 8.69/2.79	.16/ .12	42Y 8.62/2.72	.08/ .10	42Y 8.75/2.34	.10/ .09	42Y 8.65/2.70	.05/ .09
4. Strict Middling	42Y 8.66/2.22	.06/ .08	42Y 8.68/2.14	.06/ .13	42Y 8.67/2.89	.11/ .12	42Y 8.68/2.52	.09/ .18	42Y 8.66/2.10	.08/ .11	42Y 8.67/2.47	.11/ .16
5. Middling	41Y 8.42/2.07	.10/ .05	41Y 8.36/1.91	.13/ .06	41Y 8.38/2.04	.09/ .10	41Y 8.40/2.05	.13/ .09	41Y 8.40/1.92	.13/ .09	42Y 8.32/2.17	.09/ .13
6. Strict Low Middling	41Y 8.09/1.90	.08/ .10	41Y 7.96/1.63	.09/ .05	41Y 8.04/1.76	.09/ .05	40Y 8.04/1.71	.13/ .05	40Y 7.98/1.63	.11/ .10	41Y 8.02/1.95	.08/ .13
7. Low Middling	40Y 7.72/1.75	.08/ .13	40Y 7.61/1.41	.09/ .10	40Y 7.74/1.72	.09/ .05	41Y 7.74/1.85	.10/ .12	41Y 7.63/1.40	.06/ .08	41Y 7.74/1.98	.07/ .11
8. Strict Good Ordinary	41Y 7.59/1.83	.05/ .06	41Y 7.39/1.47	.14/ .05	41Y 7.54/1.79	.07/ .05	41Y 7.57/1.78	.10/ .07	42Y 7.33/1.45	.07/ .06	42Y 7.48/1.92	.09/ .08
9. Good Ordinary	41Y 7.34/1.83	.10/ .10	41Y 7.10/1.21	.11/ .10	41Y 7.38/1.70	.09/ .07	41Y 7.48/1.83	.07/ .07	43Y 7.19/1.26	.08/ .06	42Y 7.38/1.91	.09/ .09

Note how little brilliance variation there is in the high grades. The low grades have a greater variation, partly because minimum measurements are pulled down by the so-called "bluish" bales in the box. The brilliance averages for the four top grades are very nearly the same. Middling No. 5, Strict Low Middling No. 6, and Low Middling No. 7, drop considerably lower, the steps being fairly even, with a smaller brilliance drop for the two lowest grades, Strict Good Ordinary No. 8, and Good Ordinary No. 9. A great part of this brilliance change is due, doubtless, to the increasing quantity of leaf and trash present in cotton as the grades become lower.

Chroma shows a wider variation within each grade. In fact, it can be rather accurately stated that chroma differences, with the exception of the darker "bluish" bales in the low grades, are responsible for the color variations within each grade. Even in the "bluish" bales, chroma is more significant than brilliance. Chroma averages compared with grade are very nearly the reverse of those for brilliance; that is, the four top grades, instead of remaining constant as is the case with brilliance, decrease in fairly regular steps as far as No. 6, leaving the last four grades from No. 6 to No. 9, inclusive, with chroma averages which, instead of decreasing rapidly, remain very nearly constant.

Grade No. 3 is the only one in which both the brilliance and chroma measurements overlap. This is doubtless due to the increasing importance of leaf in this grade and to the fact that in certain of the samples there has been an offset of better color with more leaf. The average of the grade falls in line, but the extremes, that is, the maximum and minimum chroma, overlap, the maximum being as creamy as the maximum for grade 2, the minimum being almost as gray or weak in chroma as the average for grade 4.

In the lower grades, Nos. 7, 8, and 9, the wide chroma variation is caused by the "bluish" bales, for they are very much weaker in chroma than the average. Figure 13 shows the averages of the grades with brilliance (vertical) plotted against chroma (horizontal). About the averages are grouped the extremes, marked as to their position within the grade box. The other positions about the average may be put in by reference to Table 5. By this chart the color relation of the grades is most truly represented, although it is doubtless grasped more readily by reference to Figure 12.

Information obtained from measurements on any other product should be analyzed carefully as the foregoing analysis of the cotton measurements indicates.

IMPROVED EQUIPMENT

After these measurements were made and the results had proved them to be practicable the next step was to refine the method and equipment. A new instrument [15] has therefore been developed which has the advantage of eliminating the spinning of disks, making it easier to match the sample. When making measurements by means of this instrument, the eye need not be taken off the comparison field while the disk areas are being changed, a factor which is important in making readings easily and accurately. (See figs. 14 and 15, photographs of the instrument ready for use.)

[15] Built by Keuffel & Esser Co., Hoboken, N. J., on specification provided by this bureau.

MEASUREMENT OF COLOR IN OTHER PRODUCTS

Many other products besides cotton may be measured by this method.

The grading factor of color in the United States hay standards is based upon color measurements in terms of hue, for hue seems to be the color factor most closely correlated with grade. (With standard

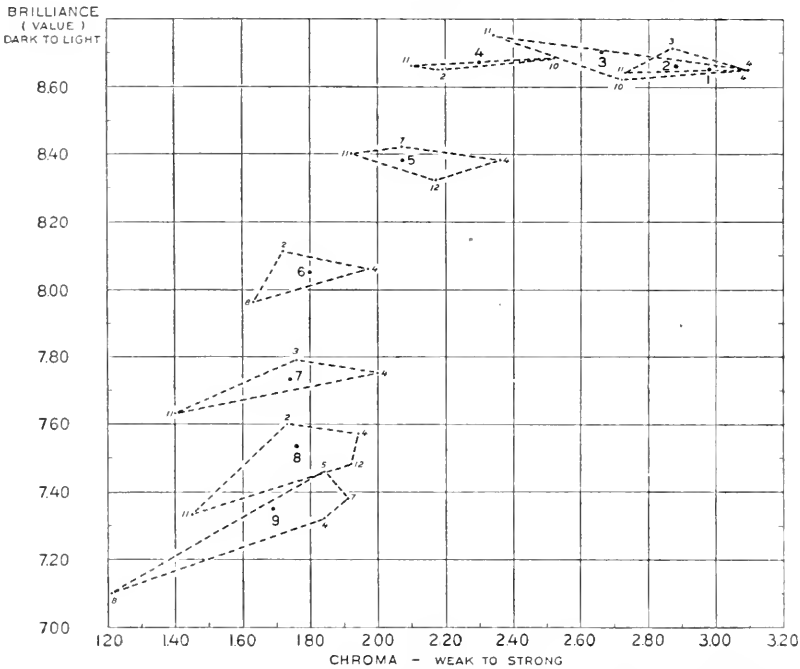

FIGURE 13.—Average readings on 10 sets of the practical forms of the standards, charted as to brilliance and chroma. The averages of the grades, together with the extremes (numbered to correspond with the position in the grade box), are shown. Note that position 4 shows in most cases the extreme amount of chroma for each grade, whereas 11 or 8 shows the least chroma. This means that in most of the grades position 4 shows the highest yellow (in the high grades by creaminess and in the lower grades by spot and sometimes slight stain) and that position 11 and 8 are the grayest bales in the grade (in the high grades the steely white bales and in the low grades the blue bales). Note that these extremes vary in their relation to the average. Whether the measurements be of cotton, flour, milk, or of anything else, the color relations indicated by a change in brilliance and chroma may be most clearly indicated by a chart of this kind

light, it is found that brillance may also be highly indicative in its relation to hue and grade.)

The first practical application to hay color work consisted of an apparatus in which the hay could be spun to get a composite color to be matched with standard cards. Figure 16 illustrates the most recent apparatus of this type.[16] This method can be used with many products, and may sometimes be advisable; but the use of a viewing unit, in which the material is put sufficiently out of focus to give a uniform color field, will accomplish the same purpose without the spinning.

[16] This machine was constructed by J. F. Barghausen, Agricultural Technologist, Bureau of Agricultural Economics.

In order to make "conversion tables" from which the grade might be read directly from a table of color readings (and this may often be advisable for many other products), a great many hay samples were graded by trained inspectors and then matched for color on the "color machine." The two sets of readings, those of the inspectors in terms of "per cent natural green color" and those made on the color machine in terms of hue, were then related in order that the

FIGURE 14.—Colorimeter developed for this work as it is set up for the measurement of cotton. The area within the black ring is measured at one time. Figure 15 shows the details of the apparatus

hue readings might be put into the inspector's language. (See Tables 6 and 7 and note that the same relations do not hold for different kinds of hay.) Equal hue differences may indicate dissimilar grade differences. Conversion tables in which two or three color factors vary may be prepared by handling the material by statistical methods of correlation.

An instrument similar to that used for cotton has been developed for hay. Note, however (fig. 17), that the field is larger in order to include a 14-inch diameter field of hay.

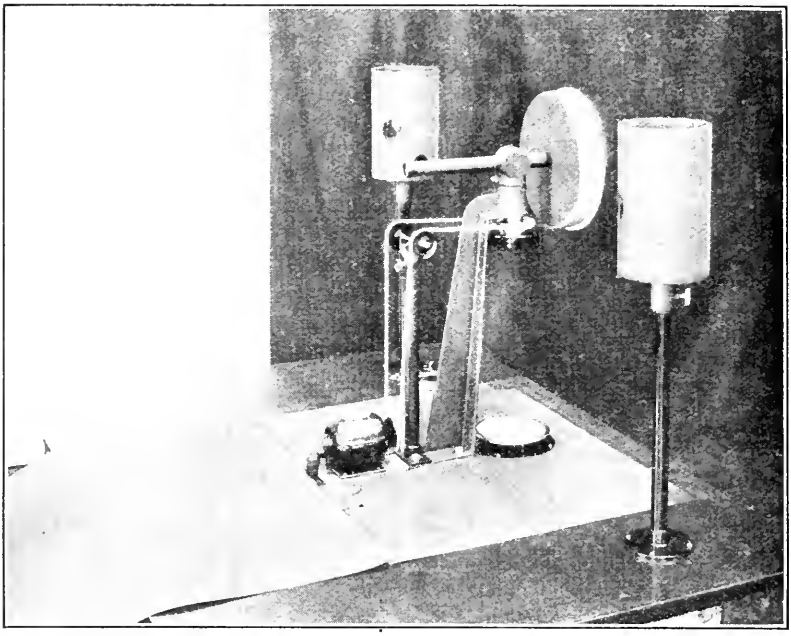

FIGURE 15.—Rear view of colorimeter, showing disks in a horizontal position. A spinning rhomb, mounted above the disks, is rotated by the pulley attached to the motor. Lamps are inclosed in the housings on either side. The black pan placed just behind the eyepiece saves the eyes from strain by enabling the observer to keep both eyes open while making readings without the chance that stray light will enter the unused eye

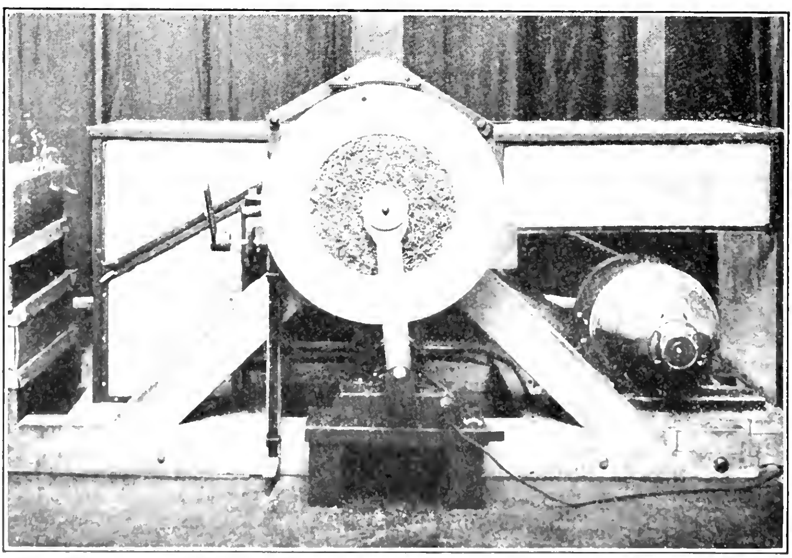

FIGURE 16.—The hay sling, placed in the machine, is ready to be spun in order that a color comparison may be made with the spinning disks. The disks are adjusted on a movable arm to a separate motor in order to avoid the necessity for stopping and starting the motor that keeps the hay sling revolving. When the disks are spun on a separate motor it is important that they run at the same number of revolutions per minute

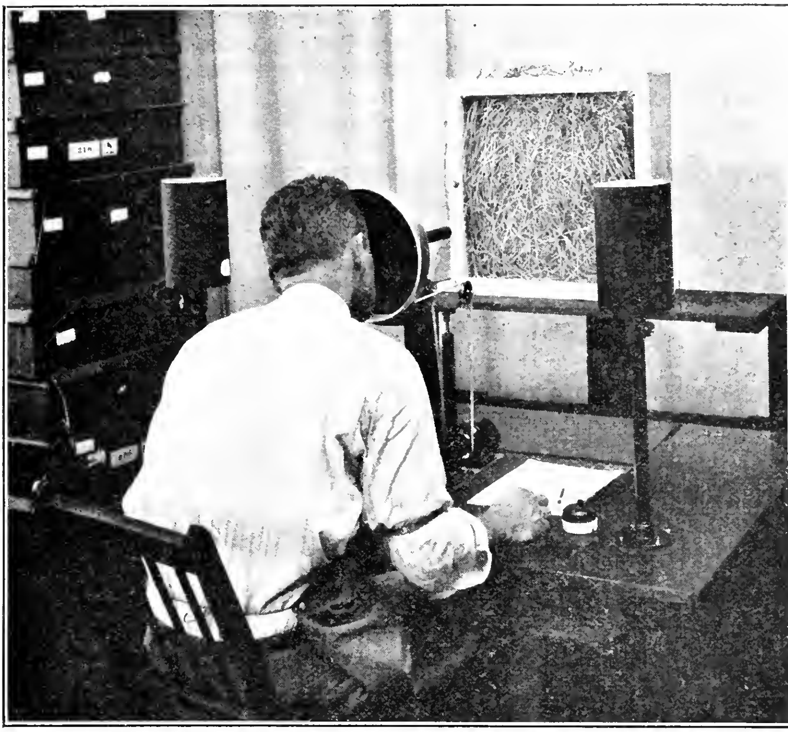

FIGURE 17.—A simplified instrument recently developed for measuring the color of hay. An area of the hay 14 inches in diameter may be measured at one time

TABLE 6.—*Conversion table for alfalfa hay showing what is called "per cent natural green color" and the equivalent Munsell hue*

"Per cent natural green color"	Munsell hue	"Per cent natural green color"	Munsell hue	"Per cent natural green color"	Munsell hue	"Per cent natural green color"	Munsell hue
0	10. 00 YR	30	3. 75 Y	55	6. 87 Y	80	10. 00 Y
5	0. 62 Y	35	4. 37 Y	60	7. 50 Y	85	0. 62 GY
10	1. 25 Y	40	5. 00 Y	65	8. 12 Y	90	1. 25 GY
15	1. 87 Y	45	5. 62 Y	70	8. 75 Y	95	1. 87 GY
20	2. 50 Y	50	6. 25 Y	75	9. 37 Y	100	2. 50 GY
25	3. 12 Y						

TABLE 7.—*Conversion table for clover hay showing what is called "per cent natural green color" and the equivalent Munsell hue*

"Per cent natural green color"	Munsell hue	"Per cent natural green color"	Munsell hue	"Per cent natural green color"	Munsell hue	"Per cent natural green color"	Munsell hue
0	7. 25 YR	30	1. 75 Y	60	4. 25 Y	90	8. 25 Y
5	8. 95 YR	35	2. 12 Y	65	4. 75 Y	95	9. 10 Y
10	. 65 Y	40	2. 50 Y	70	5. 35 Y	100	9. 95 Y
15	. 92 Y	45	2. 87 Y	75	5. 95 Y		
20	1. 20 Y	50	3. 25 Y	80	6. 55 Y		
25	1. 47 Y	55	3. 75 Y	85	7. 40 Y		

The sample of such products as can not be measured in a vertical or near-vertical plane, may be placed in a horizontal container and the equipment arranged so that the observer looks down through the eyepiece on to the sample. For instance, if any granular or semiliquid product is to be measured, such as rice or tomato pulp, a container of

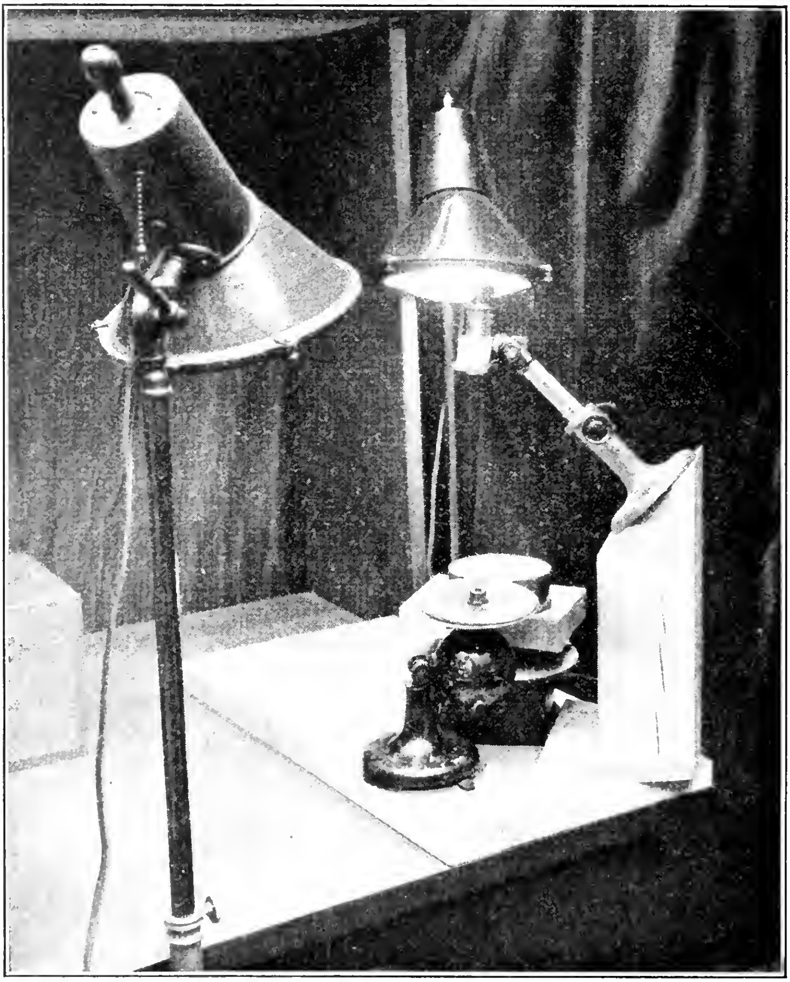

FIGURE 18.—Apparatus, similar to that shown in Figure 9, as set up for making measurements on liquids, semiliquids, or granular products, such as canned fruits and vegetables or rice and barley

the proper size should be selected and so placed that a portion of the area of the open top is visible through the eyepiece if an eyepiece is used. (Fig. 18.)

If the sample has a lustrous or semilustrous surface, the question of lighting is particularly important. Diffused lighting may give the best results, although for some work it is quite possible that, for comparison, studies should be made in both diffused light and in light at a definite angle.

It is not necessary that all color work have equally sensitive instruments with control of all environmental conditions. Just how the equipment should be set up depends upon the precision required for the work and the funds that are available. For preliminary work or for approximate studies, the simplest sort of apparatus may be used.

Ordinarily, four disks are enough for the work, the four chosen being those which, when spun, will include the extremes of the colors that are to be measured. The colors should include the two hues which are nearest to that which is to be matched, and a light and a dark neutral. For instance, in measuring tomatoes, first look at the color and decide upon the hues that must be used. Obviously one will be red, but will the other hue be a yellow-red (orange) or a red-purple? It depends upon which is the nearer to tomato coloring. Ordinarily, tomatoes will be yellowish-reds, rather than purplish-reds, so a yellow-red disk will be selected to use with the red one. Tomato colors are generally very strong in chroma, so the strongest available chromas should be selected. If there are not strong enough colors in the regular supply, then special, strong colors must be prepared.[17] It is also possible to spin either a light or a dark neutral disk before one side of the eyepiece in order that the tomato color and neutral may be alternately exposed, thus reducing or increasing the brilliance as may be necessary.

The neutrals that are selected will depend upon the brilliance of the colors which are to be measured. Tomatoes are medium to dark in brilliance. Therefore a N 1/ or 2/, nearly black, with a medium 5/ or 6/ may complete the selection of disks for tomato work.

For cotton, it is immediately evident that one hue will be yellow. The chroma of the cotton is so weak that it may not be possible to decide upon the second hue until both yellow-red and green-yellow have been tried. These hues are tried since a yellow, when departing from the standard yellow, must be either greenish or reddish. Trial will indicate that yellow-red and yellow are the hues to be used. Since the chroma of cotton is weak, a great deal of neutral color will be necessary in order to reduce the chroma of the disks, and part of that neutral will be dark, thereby reducing brilliance as well as chroma. This is not desirable, and for that reason the hues should have as strong a chroma as is possible in order to require a limited area of dark colors. Yellow has a maximum chroma of 9 on the 8 level of brilliance. Yellow-red has a maximum chroma of 8 on the 6 level of brilliance. Therefore the notation of the two hues for cotton will be Y 8/9 and YR 6/8. The neutrals to be used with these disks should contain one color which is as light as it is possible and practicable to get. This is necessary since the color of cotton is lighter than either of the disk colors selected, and a great deal of white may sometimes be necessary to counteract the darker brilliance of the yellow and yellow-red disks. The second neutral should be dark enough so that even the darkest of the colors to be measured may be included by a variation of the four disks.

Whenever it is practicable, hues of the same brilliance and chroma should be selected in order to eliminate a simultaneous change in several color factors which occurs with the change of a single area when there is a variation in the brilliance and chroma of each disk.

[17] These may not prove permanent in color, but if care is taken in using them, and spectrophotometric curves are kept as a record, they may answer the purpose satisfactorily.

Using one neutral of the same brilliance as that of the hues will also simplify the process of matching. This, however, is not often possible when a range of colors is to be measured by disks limited in number to four or five.

This selection of disks, a motor on which to spin them, and a method of holding the sample in the same plane with the disks, are all that is necessary. A mask of neutral gray with two holes of equal size, one over the sample, one over the disks, will facilitate matching. (Fig. 8.) Light from a north sky, if daylight is used, is probably the most advisable. It is important that there be no red brick walls or other reflecting surfaces near by which may add their reflections to the daylight. Table 8 indicates, from readings made at this bureau in daylight (most of them made under a north skylight) about what variation may be expected in color readings made under these conditions. The average difference between high and low readings with the standard deviation of the average, is given in Table 8. Some of the readings were made a year or two years apart on the same sample. The readings on cotton and hay were made by different experienced observers, one observer for cotton and two for hay. (These readings should be compared with those of Table 5, which were made under constant light.)

TABLE 8.—*Average difference in readings of hue, brilliance, and chroma, made in daylight*

Commodity	Samples	Average color notation (Munsell)	Difference between high and low readings in terms of 100 hue steps, 10 brilliance steps, and 10 chroma steps, with standard deviations		
			Hue	Brilliance	Chroma
	Number				
Cotton	23	4.63Y 8.09/2.73	0.70±0.42	0.22±0.13	0.43±0.23
Alfalfa hay	14	5.36Y 4.21/3.67	.44± .37	.13± .12	.20± .18
Johnson hay	15	3.52Y 4.95/3.73	.80± .38	.28± .20	.19± .15
Prairie hay	17	4.45Y 4.61/3.25	.60± .44	.31± .17	.19± .16

This method, with equipment reduced to a minimum (a toy top may be used instead of an electric motor, if the top will spin the colors) may be used for field work, as is done in matching the color of soils (*3*) both by the Bureau of Chemistry and Soils and by members of the Soils Congress. For indoor work, with north skylight, this equipment may be set up for getting measurements on the varying colors of mayonnaise, as is done in the Food Research Division of that bureau.

The next refinement of method is to add a comparison eyepiece and standard artificial light. The eyepiece makes it easier to compare colors, and standard lighting conditions eliminate changes that occur when the light varies, for natural daylight will vary from day to day and from hour to hour. A number of measurements, many of a preliminary nature, have been made with this type of equipment on cotton, cotton linters, canned corn, Lima beans, tomatoes, pulp tomatoes, barley, rice, bread, both crust and crumb (*2*), and washed cloths being studied by the Bureau of Home Economics as part of a laundry problem. The Bureau of Animal Industry is also studying the color of meat by this method as a part of a cooperative correlation study of meat quality.[18]

[18] SHEETS, E. W., A STUDY OF THE FACTORS WHICH INFLUENCE THE QUALITY AND PALATABILITY OF MEAT. U. S. Dept. Agr., Bur. Anim. Indus. Natl. Coop. Proj., 48 p. [n. d.] [Mimeographed]; Sup. to Natl. Coop. Proj. 13 p. 1928. (Mimeographed.)

If color study is important enough to be a routine part of the daily laboratory work of establishing or maintaining standards, or if it is an important part of a large correlation project, equipment should be used that will allow color measurements to be made with the utmost ease, precision, and speed. For this work such equipment is advisable as that which has been developed for the measurement of hay and cotton in this bureau. (Refer to figs. 14, 15, and 17 for illustrations.) This method of color reading allows a truly representative area of any sample, whether that area be a circle 2 inches in diameter or 14 inches, to be brought into one field, the sample being thrown out of focus so that there is one uniform field to be matched, no spots visible.

Color measurements sometimes show that hue alone is the important grade factor; sometimes it is brilliance; at other times, chroma, or a combination of any two, or of the three. If a direct relation is not apparent, a multiple correlation (*1*) may exist. Or, it is possible that color may not be a factor; in that case much future labor will be avoided by a study which will indicate this fact conclusively, for it is possible to tell whether there is a color relationship and how far the relationship holds only after measurements have been made and correlated.

SUMMARY

Methods of color measurement may be principally referred to as methods of measuring color and methods of measuring the color stimulus. One method is psychological, the other is physical; and elements of the two may be combined in what may be termed psychophysical methods. The method used in the work described in this bulletin comes under the third head, but it is interpreted in terms of the first. All methods of spectrophotometry and many methods of colorimetry come under the second. In general, methods of colorimetry may come under any of the three heads.

Color measurement of agricultural products is a distinct necessity, not alone for purposes of standardization but for determining the importance of color as a factor of their utility and value and for correlations with other factors which are important.

Experiments made on cotton are used throughout this bulletin as an example of what may be done with other products. They include spectrophotometric, photometric, and colorimetric measurements. Those measurements which were made in terms of hue, brilliance, and chroma, gave the most satisfactory results. The measurements are expressed in terms of the Munsell notation, formulas for which are developed and explained.

In order to illustrate how these color readings may be translated into terms which may be used by nonscientific workers—inspectors, graders, and other field men—the development of hay conversion tables is described.

A method for setting up and measuring a sufficiently large sample to give a representative color has been worked out, and apparatus for making careful and accurate readings has been developed and improved.

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TECHNICAL BULLETIN NO. 153 — DECEMBER, 1929

EFFECT OF MILK-PLANT ARRANGEMENT AND METHODS OF OPERATION ON LABOR REQUIREMENTS

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UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D. C.

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By C. E. CLEMENT, *Associate Market Milk Specialist;* P. E. LE FEVRE,[1] *Assistant Market Milk Specialist;* J. B. BAIN, *Associate Market Milk Specialist;* and F. M. GRANT, *Assistant Market Milk Specialist, Division of Market Milk Investigations, Bureau of Dairy Industry*

CONTENTS

INTRODUCTION

Increased costs of labor, supplies, and equipment have made it necessary for the managers of milk plants to study the methods employed with a view to increasing the efficiency and decreasing the cost of operation.

In order to determine the most efficient systems used, the Bureau of Dairy Industry has made labor studies of the operations in milk plants in various sections of the country from the time the milk reaches the plant until it is placed on the wagons ready for delivery. The amount of labor and the time required for each operation were determined.

No attempt has been made to compare the costs of different methods of operation. Labor and other costs vary greatly in different sections and at different times. The fact that a certain system is operated with the least amount of labor does not necessarily show,

[1] Mr. Le Fevre, who did a large part of the field work, resigned before the work was completed.

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therefore, that it is the least expensive. Furthermore, two plants may have the same labor costs, but one may have greater overhead expenses than the other.

RECEIVING THE MILK

The process of receiving the milk at the plant consists of transferring the cans from the receiving platform to the dump tank, removing the lids, emptying, and placing the cans on the washer or on a conveyor leading to it. The men who receive the milk inspect it before it is dumped from the cans. When the milk is weighed at the city plant they note and record the weight also. Samples are taken at regular intervals for butterfat test. Usually the men who operate the trucks place the cans of milk on the platform, but these men are not included in the labor of receiving the milk except where they help in transferring the cans to the dump tank. In some cases the men on the platform help unload the truck, but as a rule the truckmen do this work alone, placing the cans of milk on the platform or on a conveyor.

It is desirable to have the plant so arranged that the milk can be received with as small a labor cost as possible. A rapid system is also desirable so that the milk may be handled as fast as it arrives.

In many plants the cans of milk are transported by automobile or by horse-drawn trucks from the country or from the railroad station in the city to the receiving platform. From a study carried on at 63 milk plants, the following systems for receiving milk thus transported have been found:

(1) Cans are transferred from receiving-room door to weigh or dump tank by means of platform trucks. After being emptied and washed, they are returned by the same trucks to the loading-out door.

(2) Cans are taken to the second or third floor by means of the ordinary freight elevator, which accommodates about 16 cans to the load. The empty cans, after being washed, are returned by the same elevator.

(3) Cans are rolled from receiving-room door to the dump or weigh tank. This distance varies from 10 to 30 feet, but at the majority of the plants the distance is approximately 15 feet. In most cases the cans are fed directly into the washer by the man who empties the milk from the cans, although at a few of the plants another man is required to transfer the cans to the washer. At some of the plants the washer delivers the cans at a point near the door, whereas at others extra handling of cans is required at this point because of considerable distance from the delivery end of the washer to the point where they are loaded on the truck.

(4) Dump or weigh tank is located close to the receiving-room door, so that the cans are emptied with practically no handling. The washer is so located that the cans are transferred to it and out to the truck with little handling, but usually some handling is required either before or after the cans are washed. Some of the plants are so arranged that the man who empties the cans places them in the washer; whereas other plants have a space of 10 to 25 feet between the dump tank and the washer, in which case the washer usually leads directly to the loading-out door.

(5) Cans are rolled approximately 12 feet from the receiving-room door to the dump tank, and after being emptied they are placed in an automatic washer from which they are transferred to the trucks by a gravity or power conveyor.

(6) Cans are transferred from the receiving-room door to the dump or weigh tank by means of gravity or power conveyors. The cans are placed in the washer directly after being dumped, usually by the same man who empties them, there being no extra handling at this point. The washer leads to the loading-out door either directly or by means of conveyors so that there is no extra handling at this point.

(7) Same system as 6 is used, except that the cans are elevated from the street floor to a higher level by means of power conveyors or lifts and the washed cans

are returned to the street floor by a similar conveyor or lift. When the cans of milk reach the higher floor they are conveyed to the dump tank as in system 6. The cans are placed directly in the washer, from which they pass on another conveyor to the lift or to a gravity conveyor which takes them to the street floor to be loaded on the trucks.

COMPARISON OF DIFFERENT SYSTEMS AS TO TIME AND LABOR REQUIRED

Table 1 shows a comparison of the results obtained from the use of these systems at 63 milk plants. At the 23 plants using system 6 (fig. 1) the number of gallons received per hour varied from 650 to 5,685, and the number of gallons received per man-hour varied from

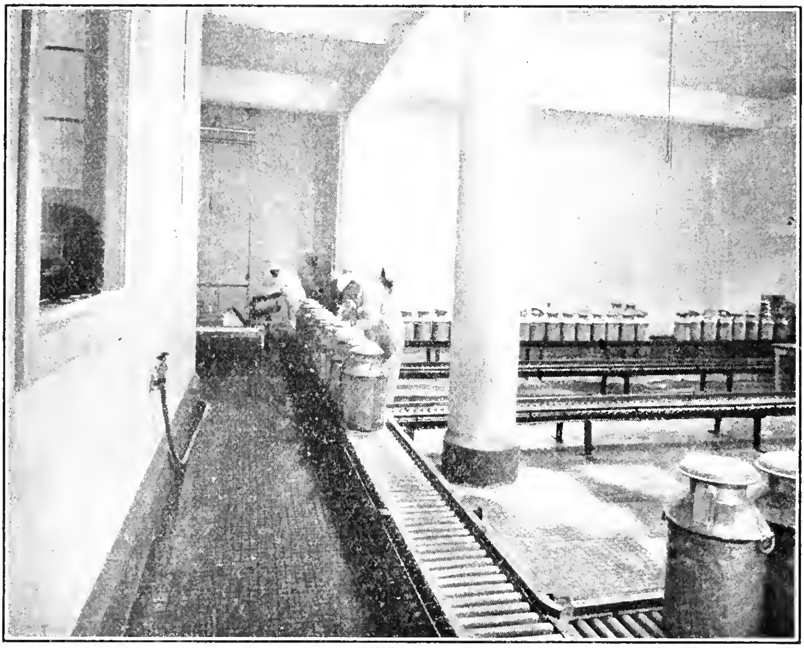

FIGURE 1.—Receiving milk at a plant using system 6. At 23 plants using systems similar to this an average of 2,334.4 gallons per hour and 459.6 gallons per man-hour was received

256.7 to 690.5, with averages of 2,334.4 and 459.6 gallons, respectively. Seventy-four per cent of the milk received at the plants in this group was weighed, and 65 per cent of the plants weighed all the milk, which is a larger percentage than in most of the other groups of plants. This system is very efficient as to labor required and is desirable for either small or large plants, unless, in the case of small plants, system 4 can be used. With system 6 the milk was received and weighed very rapidly with a small amount of labor. One plant with well-arranged conveyors received the milk at the rate of 708.8 cans per hour and 71.9 cans per man-hour.

TABLE 1.—*Comparison of the results obtained from the use of seven systems of receiving milk at 63 plants*

System [1]	Plants	Milk handled daily per plant		Help employed per plant	Time required		Milk received per— Hour		Milk received per— Man-hour	
	Number	*Gallons*	*Cans* [2]	*Number*	*Hours*	*Man-hours*	*Gallons* [3]	*Cans* [3]	*Gallons* [3]	*Cans* [3]
1	3	5,083	525	4.0	5.2	17.3	983.9	101.6	293.3	30.3
2	2	5,435	544	4.5	5.5	24.5	988.1	98.8	221.8	22.2
3	20	1,399	509	3.5	4.1	15.2	1,079.6	124.8	289.9	33.5
4	7	5,433	549	2.4	3.6	8.9	1,506.1	152.1	613.4	61.9
5	3	14,042	1,367	3.3	6.3	25.7	2,217.1	215.8	547.1	53.3
6	23	9,642	1,172	4.6	4.1	21.0	2,334.4	283.2	459.6	55.9
7	5	16,220	1,576	6.8	6.9	47.4	2,353.6	228.8	342.2	33.3

System [1]	Time required to receive— 100 gallons		Time required to receive— 100 cans		Milk weighed at plant	Plants weighing milk
	Minutes [4]	*Minutes* [3]	*Minutes* [4]	*Minutes* [3]	*Per cent*	*Per cent*
1	6.0	6.1	57.6	59.1	36.1	33.3
2	6.3	6.1	62.4	60.7	100.0	100.0
3	6.6	5.6	60.2	48.1	55.8	60.0
4	5.3	4.0	50.5	39.5	22.4	28.6
5	3.0	2.7	31.7	27.8	0.0	0.0
6	3.9	2.5	36.2	21.2	74.1	65.2
7	3.0	2.6	29.6	26.3	31.6	40.0

[1] For descriptions of these systems, see p. 1.
[2] Most of the milk was received in 10-gallon cans but other sizes were used in some cases.
[3] True or weighted average.
[4] Average of averages.

System 1 was not a common system, and the table shows that it was not an efficient one. The smallest number of gallons per hour was received at the three plants using this system. The number of cans received per hour was slightly greater than at the plants using system 2. This was due, however, to the fact that at plants using system 1 a number of small-sized cans were used, whereas at the plants using system 2 only 10-gallon cans were used. With the exception of the plants using systems 2 and 3, those using system 1 received the smallest quantity of milk per man-hour.

Extra men and time were required at the plants using system 2 because of the transferring of milk from one floor to another. There were well-arranged conveyors on the second floor for bringing the milk to the dump tank and the cans from the washer. An average of only 98.8 cans per hour and 22.2 cans per man-hour was received at the two plants using this system.[2]

At the 20 plants using system 3 (fig. 2) an average of only 1,079.6 gallons of milk per hour and 289.9 gallons per man-hour was received. The average time required to receive 100 gallons of milk varied from 3 to 17.3 minutes, with an average of 6.6 minutes. Because of the small size of the plant, only one man was used at the plant requiring 17.3 minutes per 100 gallons, and the number of gallons received per man-hour was greater at this plant than at the average plant of the

[2] Similar results were reported in the following publication: KELLY, E., and CLEMENT, C. E. CITY MILK PLANTS: CONSTRUCTION AND ARRANGEMENT. U. S. Dept. Agr. Dept. Bul. 849, 35 p., illus. 1920. This bulletin shows that at four plants using this system an average of 101.5 cans was received per hour.

group. The number of gallons received per day at the plants in this group varied from 1,200 to 11,250, with an average of 4,399. This system of receiving milk appears to be desirable only for those plants that are unable to adopt either system 4 or 6. System 3 required much extra handling, which could be eliminated by having the weigh can near the receiving-room door or by installing a well-arranged conveyor to the weigh can and from the can washer.

Most of the plants using system 4 (fig. 3) were small. There was, however, one large plant, which received 13,500 gallons of milk per day. This was handled and the cans washed by 4 men in four hours, thus making an average of 3,375 gallons per hour and 843.8 gallons per man-hour. Many large plants are so arranged that this system

FIGURE 2.—Receiving milk at a plant using system 3. An average of 289.9 gallons per man-hour and 1,079.6 gallons per hour was received at 20 plants using this sytem

can not be conveniently used, but for small plants it is very satisfactory. An average of only 2.4 men, varying from 2 to 4, was used per plant. This was the smallest number used with any of the systems.

The three plants using system 5 ranked higher than those using system 4 in the number of gallons of milk received per hour. Although the plants using the former system were larger than those using the latter, more men were used, resulting in a smaller number of gallons received per man-hour. None of the milk at the plants using system 5 was weighed, for which reason less labor was required. A larger average daily quantity of milk was received at the plants using system 5 than was received by any other plants except those using system 7. This is true also of the average number of hours required per plant to receive the milk.

System 7 required more labor than did system 6, as extra men were needed to put the cans of milk on the lift and to take off the empty cans. Therefore, although more milk was received per hour than with the other systems, the number of gallons received per man-hour was considerably less than with some of the other systems. No milk pump was required at the plants using this system, as the milk flowed by gravity from the dump and receiving tank through the pasteurizing outfit to the bottle fillers. This is a desirable system for large plants which are so arranged that it is preferred to receive the milk on a higher floor and where it is not desired to use a milk pump; but, as is shown in Table 1, considerable labor could be saved if the milk were weighed on the street floor and system 6 or even

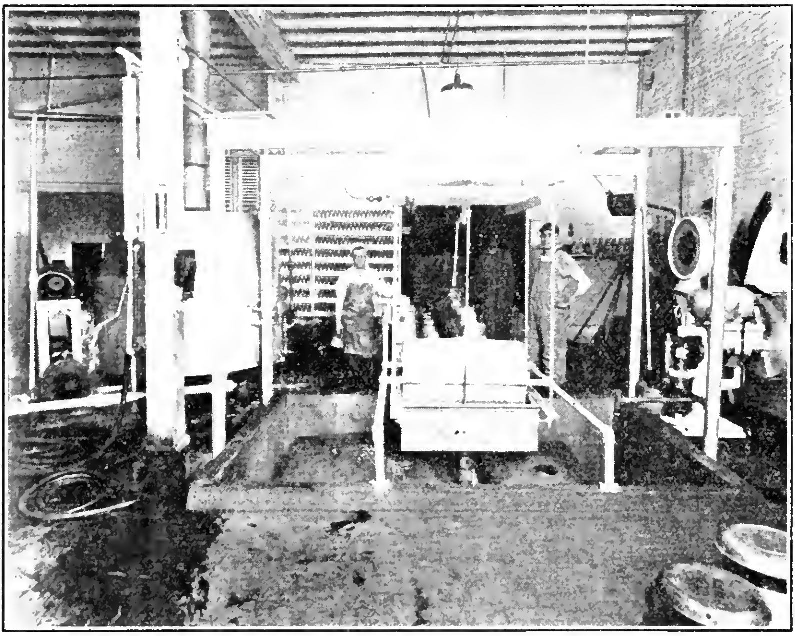

FIGURE 3.—Receiving milk at a plant using system 4. At seven plants using this system an average of 1,506.1 gallons per hour and 613.4 gallons per man-hour was received

system 5 used. The plants using system 7 required an average of 6.8 men, a much higher average than was required under any other system.

When all factors are considered, system 6 seems to be the most efficient one. Although at the particular plants studied less milk was received per man-hour than at plants using systems 4 or 5, more was received per hour than with either system 4 or 5, and more cans of milk were received per man-hour than at plants using system 5, there being fewer of the smaller-sized cans at the latter plants. Furthermore, system 6 is the most adaptable to plants having various arrangements of equipment. The plants using system 4 required the least number of men, but these plants were smaller than most of the others studied. Systems 1, 2, and 3 were the lowest in average number of gallons handled per hour and per man-hour.

COMPARISON WITH OTHER METHODS OF RECEIVING MILK

During recent years increasingly greater quantities of milk have been transported to the city in large tanks mounted either on automobile trucks or on railroad cars. Where the railroad car can be loaded at the country plant and can be switched on a siding to the plant in the city, it is used to a considerable extent. In other cases the tank truck is used to transfer the milk from the country plant or from the tank car in the city railroad yard to the city plant.

In some sections of the country full carloads of milk in cans are switched to the city-plant receiving platform and the cans transferred directly from the car to the plant receiving room. In some cases the cans of milk are transferred by means of platform trucks from the cars to the receiving room (fig. 4), and after the cans are emptied and washed they are returned to the car by truck, or they are carried by the men. In other cases a dump tank is placed in the car and con-

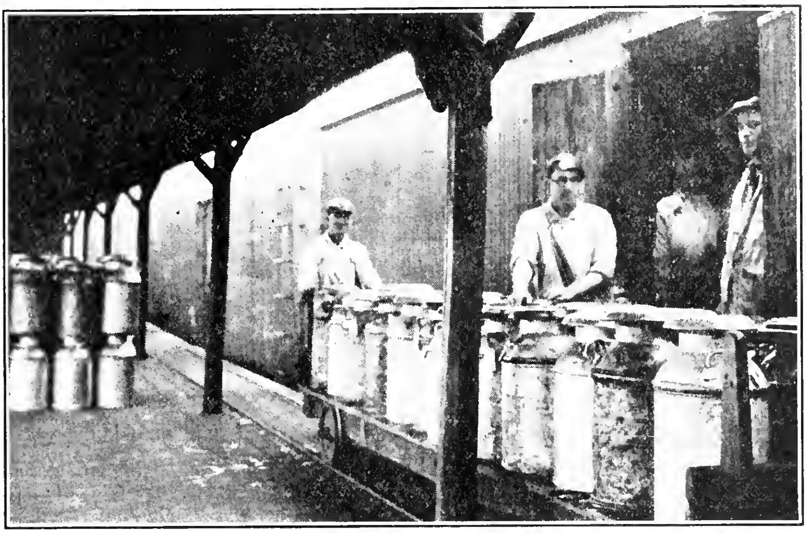

FIGURE 4.—Unloading milk from cars switched alongside plant receiving platform

nected with the receiving tank in the plant by sanitary piping, and the cans are emptied before being removed from the car. These cans are then transferred to the can-washing room, and after being washed they are returned to the car.

In Table 2 a comparison is made of the time and labor required at 123 plants, 91 of which received the milk in cans from trucks, which is the method used at the plants previously described (method 1); 24 of which received the milk from tank trucks or cars (method 2); and 8 of which received it in cans from cars switched alongside the plant receiving platform (method 3).

An average of only 1,540 gallons of milk per hour and 197 gallons per man-hour was received at the plants using method 3. The quantity received per hour was nearly as great as that received at plants using method 1, but the quantity received per man-hour was much less because of the fact that a large number of men were required to transfer the milk and cans from place to place. The method of receiving milk directly from the cars at the plant appears to be very desirable, as it eliminates trucking from the railroad yards. Moreover, by the use of a properly arranged conveyor system, such as some of the plants using method 1 have, it should be possible to reduce the labor required at these plants. On account of the long railroad siding required, however, most of the plants using method 3 are long and narrow. (Fig. 5.) In this type of plant it is often very difficult to effect a convenient and efficient arrangement. At these plants the labor includes not only the removal of the cans of milk from the car but also the return of the empty cans to the car. This latter work is not included in the labor at the plants using method 1. In comparison with the plants using the other two methods, the number of men required in the plants using method 3 was excessively large.

TABLE 2.—*Comparison of the results obtained from three methods of receiving milk at 123 plants*

Method	Plants	Milk received daily per plant	Help employed per plant			Milk received per—		Time required to receive 100 gallons		Milk weighed at plant	Plants weighing milk
			Men	Time required		Hour	Man-hour				
	Number	*Gallons*	*Number*	*Hours*	*Man-hours*	*Gallons* [1]	*Gallons* [1]	*Minutes* [1]	*Minutes* [2]	*Per cent*	*Per cent*
(1) In cans from trucks	91	7,328	3.9	4.6	19.1	1,565	384	3.8	5.7	63.8	64.8
(2) From tank trucks or tank cars	24	8,102	1.5	4.4	6.2	1,834	1,309	3.3	3.7	38.8	33.3
(3) In cans from cars switched along plant receiving platform	8	9,145	8.4	5.9	46.5	1,540	197	3.9	4.1	22.0	25.0

[1] Weighted average. [2] Average of averages.

At the 24 plants receiving the milk in tank trucks or cars an average of 1,309 gallons was handled per man-hour. This is more than three times as much as the average amount handled per man-hour at the plants using method 1 and more than six times the average amount handled by the plants using method 3. The method of receiving from tank trucks or cars requires much less labor than does receiving the milk in cans, as the washing and steaming of the tanks is a small task compared with the washing of the large number of cans. Furthermore, the milk is transferred from the tanks to the weigh can or receiving tank by pump, gravity, or air pressure, so that no handling is required.

CHECKING IN THE ROUTES

The operation of verifying the driver's count of empty bottles and unsold goods and keeping the platform clear is called "checking in the routes." As a rule, the driver sets the bottles on the platform or on conveyors or trucks, if they are used; and the checker, after verifying the driver's count, transfers the bottles to another point. In some cases, however, he transfers the bottles from the platform to the conveyors or trucks. He also usually dumps or otherwise takes care of the unsold goods which are returned. The time required for the latter work, however, is not included in the time required to check in the routes. From a study carried on at 82 plants, the following classifications have been made of the systems used in checking in routes:

(1) Bottles are checked in on a gravity conveyor which leads to the bottle-washing room or an adjoining storage room where they are stacked by the checkers. They are later removed from the stacks by the bottle-washing crew and transferred to the washer or to a conveyor leading to it. This system is used at plants where the bottles are not checked in and washed in one continuous operation.

(2) Bottles are put on one or more conveyors by the drivers, and after the count has been verified they pass direct to the washers and are washed immediately. A small proportion of the bottles, however, must be stacked because the pints and quarts can not be washed at the same time.

(3) Bottles are put on one conveyor by the drivers, and after the count is verified they go direct to the washer. Many of the bottles, however, must be stacked because they come in too fast for the washer to handle, since in practically

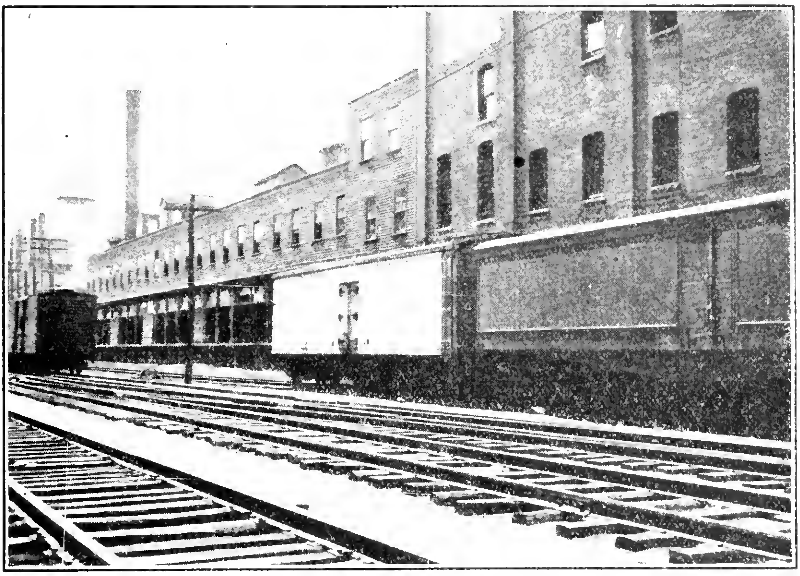

FIGURE 5.—Type of plant used where milk is received in cans from cars switched alongside of plant

all the plants in this group only one bottle-washing unit is used. Stacking is also necessary in most of the plants because pints and quarts can not be washed at the same time.

(4) Same as system 3 except that two or more conveyors are used. In some cases all the bottles from one wagon are unloaded at one conveyor, whereas in others pints are unloaded at one conveyor and quarts at another. In either case two or more routes may be checked in at the same time. The continuous or direct system of washing and filling is generally used.

(5) Bottles are unloaded and checked on the receiving platform at three or more points. Quart bottles are usually checked in at one point, pints at another, unsold goods at another, and so on, the driver going from one point to the next and several routes being checked in at the same time.

(6) Bottles are unloaded and checked on the platform close to the washer so that very little transferring is required. This system is adaptable only to small plants where the washer can be located in close proximity to the checking-in platform.

(7) Bottles are unloaded and checked on the platform, and the stacks of bottles are dragged back with hooks or by hand by the checkers to the washing room or adjoining storage space. As this is a slow process, the routes can not be checked

in at a very rapid rate. Since the washing room is usually nearby, the distance that the stacks of bottles must be transferred is short.

(8) Bottles are checked in and stacked on the platform and are then sent on conveyors to the washers by the checkers. At two of the three plants in this group the bottles were sent to another floor to be washed. At another plant they were checked in on a long platform at a considerable distance from the washing room. The two departments were so located, however, that the bottles could not pass in a straight line directly from the checking-in platform to the washer, as in the case of systems 2, 3, and 4. At this plant several routes could be checked in at the same time.

(9) Bottles are checked in on the platform and transferred to the washing room or adjoining storage space by means of lift trucks, dolly trucks, or the ordinary 3-wheel or 4-wheel platform trucks. The lift trucks consist of platforms with skids under which a wheel truck is run; the platform is raised by the lever of the truck; and it, with the full load of bottles, is wheeled away to the washing or storage room. The dolly truck is a small truck with small wheels or castors. Four stacks of bottles can usually be piled on this truck, which is then pushed away by hand.

(10) Bottles are checked in and stacked on the platform and transferred to the washing room or adjoining storage space by means of the ordinary barrel or warehouse truck, which usually carries six or seven cases to a load. This type of truck may have an attachment by means of which a man can readily transfer bottles stacked 10 cases high. At the particular plants studied, however, none of this latter type of trucks were in use. The bottles are usually checked in and stacked on a long platform, several routes often being checked in at the same time.

TABLE 3.—*Comparison of the results obtained from the use of 10 systems of checking in routes at 82 plants*

System	Plants	Routes per plant			Checking-in requirements			
		Wholesale	Retail	Total	Men	Hours	Man-hours	Per route
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Minutes*
2	8	2.1	71.1	73.2	2.8	3.2	9.0	2.7
6	7	.3	21.7	22.0	1.3	2.8	3.3	7.6
5	4	-------	152.3	152.3	7.0	3.8	27.0	1.5
3	18	5.0	57.9	62.9	2.5	4.3	11.4	4.5
7	11	2.5	30.0	32.5	1.9	2.9	6.3	5.3
4	5	8.6	93.2	101.8	5.8	4.2	25.4	2.5
1	12	4.8	58.5	63.3	3.4	4.8	16.7	5.2
9	10	7.0	39.4	46.4	3.2	4.6	12.8	5.9
10	4	18.0	46.0	64.0	3.0	6.6	20.2	6.2
8	3	10.3	60.7	71.0	5.0	5.2	25.5	4.4

System	Routes checked in per—		Man-hours sorting and getting bottles to washer		Routes per man-hour [2]	Time required per 100 routes for—	
	Hour	Man-hour	Number	Per cent [1]		Checking in alone	Checking in including sorting and getting bottles to washers
	Number	*Number*			*Number*	*Man-hours*	*Man-hours*
2	22.5	8.1	9.1	50.3	4.1	12.4	21.4
6	7.9	6.7	1.1	29.8	1.7	14.9	21.3
5	10.6	5.6	27.6	50.5	2.8	17.9	35.7
3	11.5	5.5	11.1	49.3	2.8	18.2	35.7
7	11.1	5.2	5.8	47.9	2.7	19.2	37.0
4	21.5	4.0	19.8	43.8	2.3	25.0	43.5
1	11.5	3.8	14.8	47.0	2.0	26.3	50.0
9	10.1	3.6	16.2	55.9	1.6	27.8	62.5
10	9.7	3.2	22.9	53.1	1.5	31.3	66.7
8	13.7	2.8	27.7	52.1	1.3	35.7	76.9

[1] Per cent of total man-hours used for checking in, sorting, and getting bottles to washers.
[2] Including sorting and getting bottles to washers.

COMPARISON OF DIFFERENT SYSTEMS AS TO TIME AND LABOR REQUIRED

Table 3 shows the results of a study of the systems used in checking in routes at 82 plants. The table is arranged according to the efficiency of the systems in respect to the number of routes checked in per man-hour.

In the last column of this table are shown the total number of man-hours required to check in 100 routes, to sort the bottles, and to get them to the washer. This is the most important column in the table by which to determine the most economical system of checking in routes as regards labor. In some plants the routes may be checked in at a low labor cost, but much additional labor may be required to transfer the bottles from the checking-in platform to the bottle

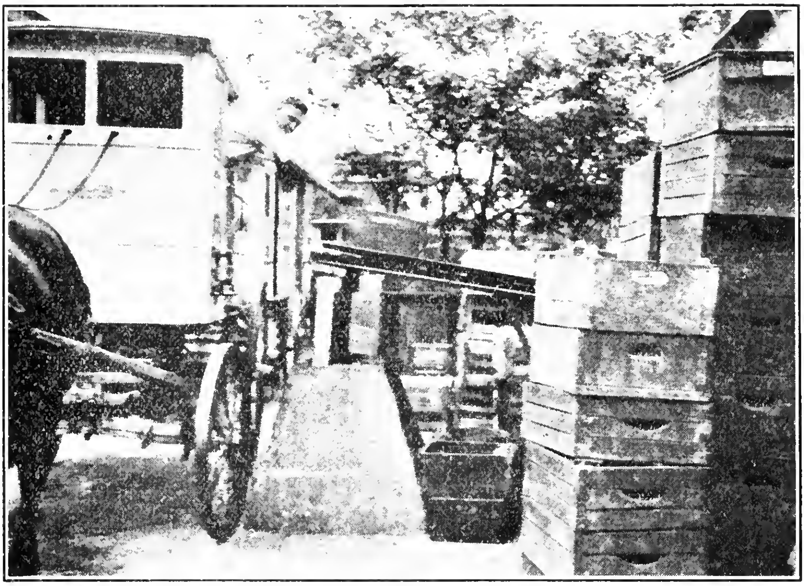

FIGURE 6.—Unloading bottles on a conveyor at a plant using system 2. An average of 22.5 routes per hour and 8.1 routes per man-hour was checked in at eight plants using this system

washers, in which case the system can not be considered economical of labor.

System 2 (fig. 6) was the most economical in respect to the labor required for actual checking in. Plants of all sizes used this system, the number of routes per plant varying from 9 to 144. At 5 of the plants 1 conveyor was used, at 2 plants 2 conveyors were used, and at 1 plant 4 were used. At the plant using 4 conveyors, the routes were checked in at the rate of 60 per hour. The average length of time required to check in the routes at all the plants was only 3.2 hours. The plants using system 2 checked in more routes per hour than did any others except those using systems 4 and 5.

An average of only 2.8 men per plant was used for checking in with system 2, and more routes were checked in per man-hour than with any of the other systems. Only a small amount of handling and very little storage space were required. Only system 6 required fewer man-hours per 100 routes than did system 2 to check in the routes and to get the bottles to the washer.

At plants using system 6 the routes were checked in at the rate of 6.7 per man-hour, and only 21.3 man-hours were required to check in 100 routes and to get the bottles to the washer. Fewer routes were checked in per hour, however, with this system than with any other, and it is adapted only to small plants.

System 5 was found to be the most efficient in regard to the number of routes checked in per hour. (Figs. 7 and 8.) The average number of routes at the four plants using this system was 152.3, the number varying from 120 to 190. At these plants, because of their size, it was necessary to check in a large number of routes in a limited time, and more men were required than were required at plants using other systems. Some of the plants had as many as five unloading points, which permitted five routes to be checked in at the same time. This necessitated at least one man at each unloading point. The number of routes checked in per man-hour was therefore less than at plants

FIGURE 7.—Checking in routes at a plant using system 5. An average of 40.6 routes was checked in per hour at four plants using this system

using some of the other systems. Considerable labor was required to get the bottles to the washer, an average of 35.7 man-hours being required to check in 100 routes, sort the bottles, and get them to the washer. At some of these plants conveyors led from each unloading point to the washers, whereas others were so arranged that the bottles were first stacked on the platform and later sent to the washing room on conveyors. Considerable storage space for dirty bottles and ample platform space were required when this system was used. It was found primarily at plants the arrangement of which was such that other systems could not be adapted to them.

The plants using system 3 checked in practically as many routes per man-hour as those using system 5. System 3 was the most popular one, there being 18 plants in this group. Fewer men were required than with some of the other systems, an average of only 2.5 men per plant being used in checking in routes and stacking bottles. More than twice as many men were used at the plants using system 4 (with two conveyors), although considerably more routes were checked in per hour with the latter system. As a large proportion of the bottles were stacked, considerable storage space was required, and a large amount of labor was used in getting the bottles to the washer. An average of 35.7 man-hours per 100 routes was required in system 3 to check in and to get the bottles to the washer. The average number of routes at the 18 plants using system 3 was 62.9, the number varying from 21 to 120.

System 7 was the next most efficient system as to labor required per route. (Fig. 9.) Fewer men were required than with most of the other systems, but it is adaptable only to small plants. Considerable labor was required to get the bottles to the washer, and much storage space for the bottles was necessary. Although an average of only 19.2 man-hours was required to check in 100 routes, 37 man-hours

FIGURE 8.—A line of wagons waiting to be checked in at the plant shown in Figure 7

was required when the labor of getting the bottles to the washer was included.

With system 4 fewer routes were checked in per man-hour than with system 3, where only one conveyor was used, but considerably more were checked in per hour, as many as 30 routes per hour being checked in at some of the plants. This system is better adapted to large plants than is system 3. The five plants studied varied from 41 to 140 in number of routes and averaged 101.8. Less storage space for dirty bottles and less labor in getting the bottles to the washer were required than with some of the other systems.

System 1 required a good deal of labor both for checking in the routes and for getting the bottles to the washer. An average of only 3.8 routes was actually checked in per man-hour, and only 2 per man-hour when the labor required to get the bottles to the washer was included. Considerable storage space for the bottles was also required.

System 9 (fig. 10) was not economical in number of routes checked in per hour and per man-hour and in number of men used. An average of 62.5 man-hours per 100 routes was required for checking in and getting the bottles to the washer. Considerable storage space for the bottles was also necessary. Although as a rule this system is not economical in the number of routes checked in per hour and per man-hour and in the number of men required, it is as well adapted to some small plants as is the conveyor system.

The principal advantage of the use of trucks, such as those used with system 9, over the use of conveyors is that the checking of the returned bottles is facilitated and there is less likelihood of difference between the checkers' and drivers' counts. When the full load is placed on one truck the driver can readily see how many bottles he has; whereas when they have passed on a conveyor with returns

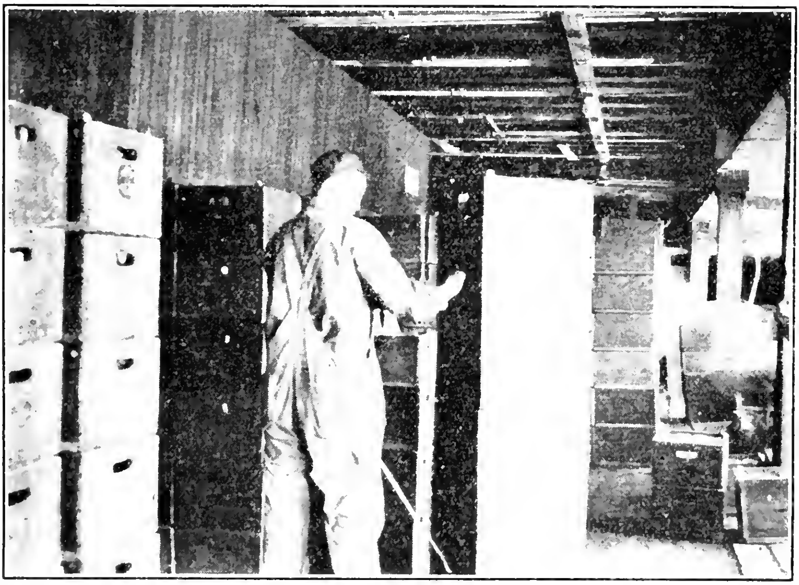

FIGURE 9.—Checking in routes at plant using system 7. At 11 plants using this system an average of 11.4 routes was checked in per hour

from other routes, mistakes are sometimes made, and a recount is very difficult.

System 10 was one of the least economical systems both as to time and labor required. (Fig. 11.) Since the four plants using this system were all located in the same city, its use seems to be the result of custom rather than of economy. The fact that end-door delivery wagons were used at these plants also seems to be one reason for the use of this system of checking in routes, as some of the other systems were not so well adapted for receiving the bottles from end-door wagons.

System 8 was not commonly used, as is shown by the small number of plants in this group. It was not economical so far as the use of labor is concerned, as there was a great deal of transferring of bottles. An average of 35.7 man-hours per 100 routes was required for checking in alone, and an average of 76.9 man-hours when the labor of getting the bottles to the washer was included.

Figure 12 shows the relation between the number of man-hours required for checking in alone at plants using the systems previously described and the total number of man-hours required for checking in the routes, sorting the bottles, and getting them to the washer. The systems are arranged in order of greatest economy as to labor required for checking in alone.

Figure 12 shows that a comparatively large amount of labor was required to get the bottles to the washers at the plants using systems 1, 9, 10, and 8. With system 1 considerable time was used to transfer the bottles from the storage room to the washer. Since trucks were used with systems 9 and 10, much handling was necessary before the bottles reached the washers. In the case of system 8, the large number of extra men required in getting the bottles to the washers was due

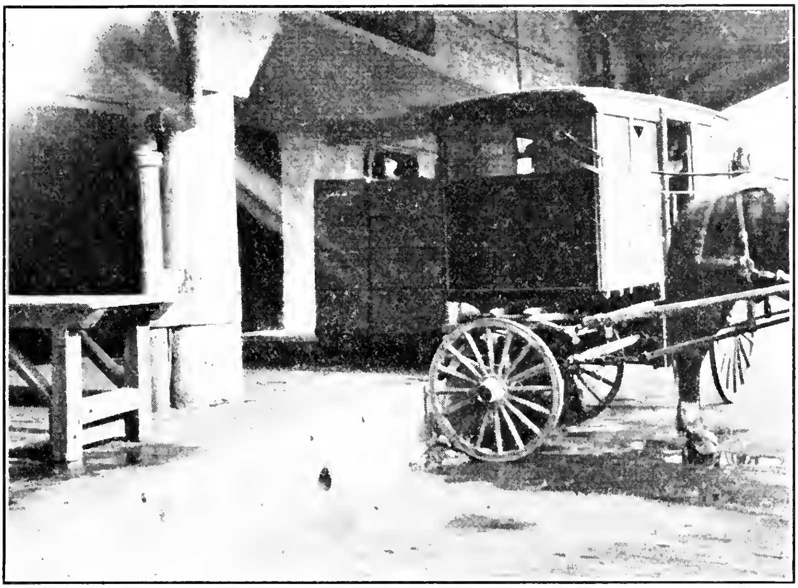

FIGURE 10.—Checking in routes at a plant using system 9. An average of 10.1 routes was checked in per hour at 10 plants using this system

to the transferring from the stacks to the conveyors leading to the washers. Only a small amount of labor was required to get the bottles to the washer at the plants using system 6 because with this system the bottles are unloaded close to the washer.

RELATION OF SIZE OF PLANT TO SYSTEM USED

It is desirable for plants of all sizes to employ a system by which all routes can be checked in in at least four or five hours. As a rule the large plants have adopted systems which are the most economical in the use of time. Figure 13 shows the relation of the size of plant to the system used at the plants studied. Dotted line A–B connects the blocks representing the average number of routes operated by the groups of plants using the various systems of checking in and dotted line C–D connects the blocks representing the average number of routes checked in per hour by these systems.

The lines are far apart for systems 8, 10, and 1, and they are very close together for systems 6 and 7. Systems 8, 10, and 1 are less efficient as to time required per route than would be expected from the number of routes at the plants in these groups. As before stated, the use of system 8 is due more to the peculiar arrangement of the particular plants than to the economy of the system. The plants using system 1 were not so arranged and the operations were not so coordinated that the bottles could pass directly to the bottle washers from the checking-in platform. As before stated, the use of system 10 is restricted to a certain locality where custom and the use of end-door wagons seemed to be the principal reasons for its existence.

Systems 6 and 7, at which the dotted lines in the figure come very close together, are adaptable only to small plants. Where only a

FIGURE 11.—Checking in routes at a plant using system 10. An average of only 9.7 routes per hour and 3.2 routes per man-hour was checked in at four plants using this system

few routes are to be checked in, there is no necessity for installing conveyors or for any special arrangement as long as the bottle washer is close to the receiving platform. System 7, as the lines in the figure indicate, is used at slightly larger plants than is system 6. This is due to the fact that with the former system the cases of bottles are pulled out of the way immediately.

BOTTLE WASHING AND FILLING

Bottle washing and filling are two of the most important operations in the milk plant. The amount of labor used in washing and filling bottles at 104 plants was found to be nearly 50 per cent of that required for all the principal operations, including receiving milk, washing cans, pasteurizing and cooling, storing the milk, and loading and unloading delivery wagons.

A study of the operation of bottle washing and filling in milk plants to determine the relative merits of the systems used entails the con-

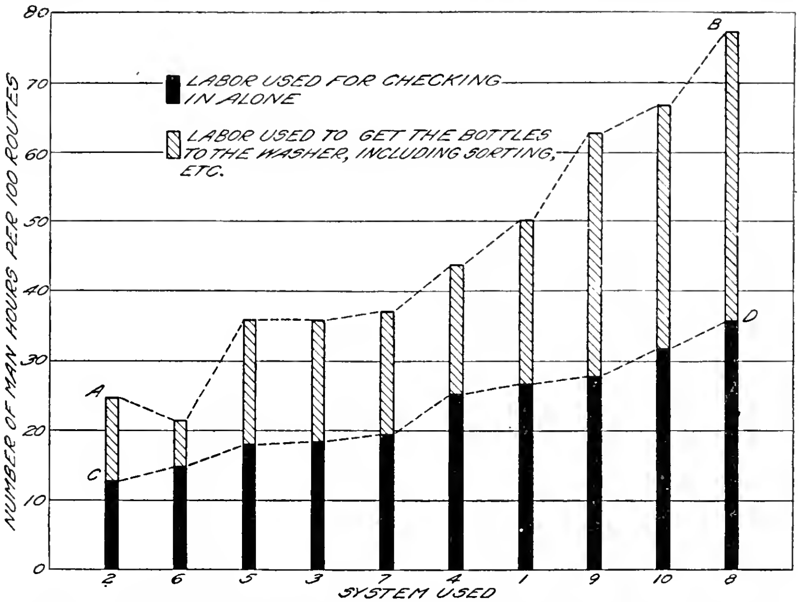

FIGURE 12.—Comparison of the labor required for checking in alone (C–D) with that required for checking in the routes, sorting the bottles, and getting them to the washers at plants using various systems (A–B)

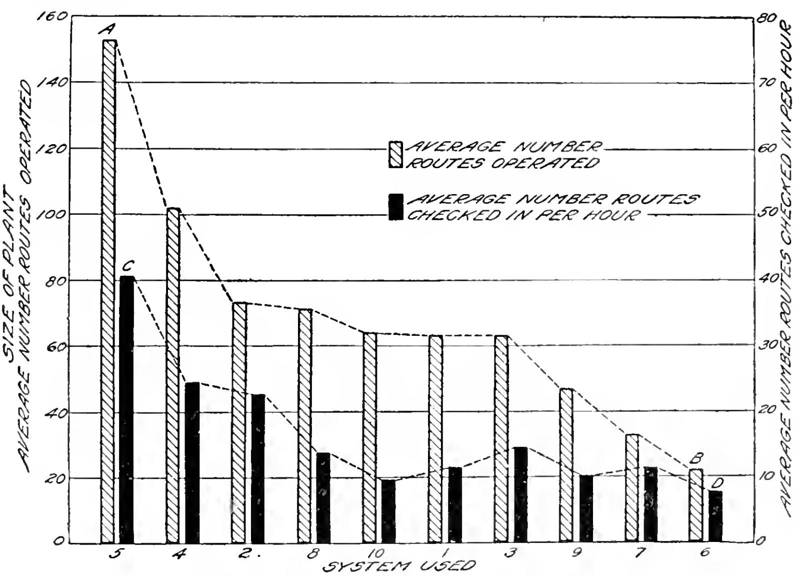

FIGURE 13.—Relation of average number of routes checked in per hour (C–D) to the size of plant (A–B)

sideration of a number of factors, the most important of which are as follows: (1) Method of checking in the bottles from the routes;

(2) whether or not the bottles are sorted, and if so, the number of men required; (3) method of getting the bottles from the checking-in platform to the washers, from the washers to the fillers, and from the fillers to the storage room; (4) number and type of machines used; and (5) number of men used for inspection.

Studies made at 171 milk plants showed a great variation in the amount of labor required at plants using different systems of getting the bottles to the fillers. The following three systems were considered: Direct, indirect, and semidirect. In the direct system (figs. 14, 15, and 16), no handling of bottles between the washers and fillers is required. After being removed from the cases, the bottles are washed and sterilized and are then cooled in the washer, from which they pass automatically on conveyors direct to the fillers.

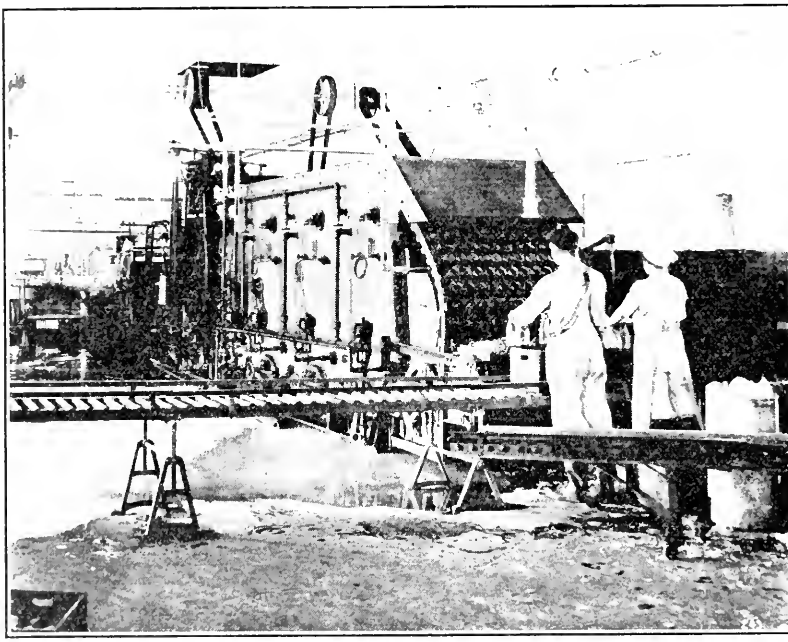

FIGURE 14.—Feeding bottles to the washer where the direct system of washing and filling is used. The bottles pass from the washer on conveyors directly to the fillers

In the indirect system (fig. 17) the bottles, after being washed in the cases, are stacked either in the bottle-filling room or in a special clean-bottle storage room and allowed to cool, after which they are removed from the cases and fed into the fillers by hand. Thus this system not only requires considerably more labor in handling bottles than does the direct system, but it offers a greater chance for the bottles to become contaminated, either while in storage or by the hand feeding to the fillers.

Only a few plants use the semidirect system. These plants use the same types of bottle washers as are used with the indirect system except that a cooling arrangement is attached. As soon as the bottles have been washed and sterilized, they are cooled in the cases, after which they pass on conveyors to the fillers, where they are removed from the cases and fed to the machines by hand.

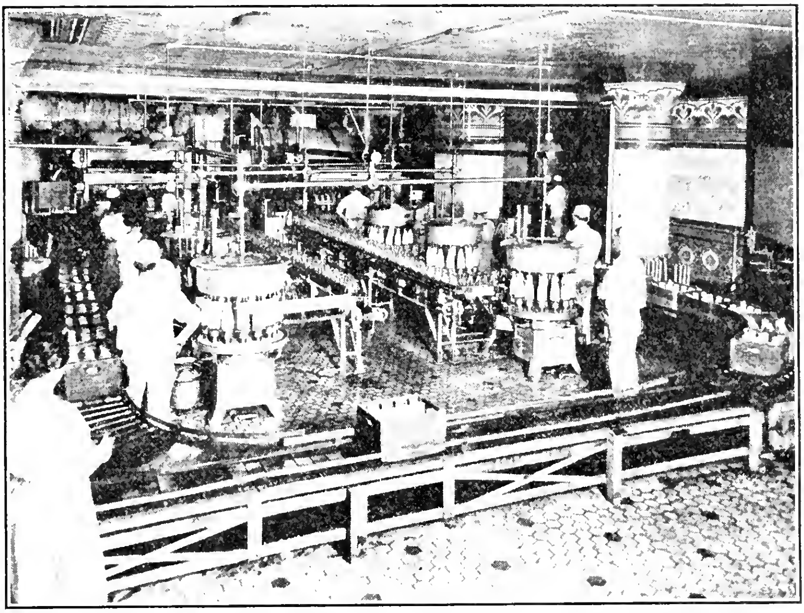

FIGURE 15.—Filling the bottles at a plant using the continuous or direct system of washing and filling

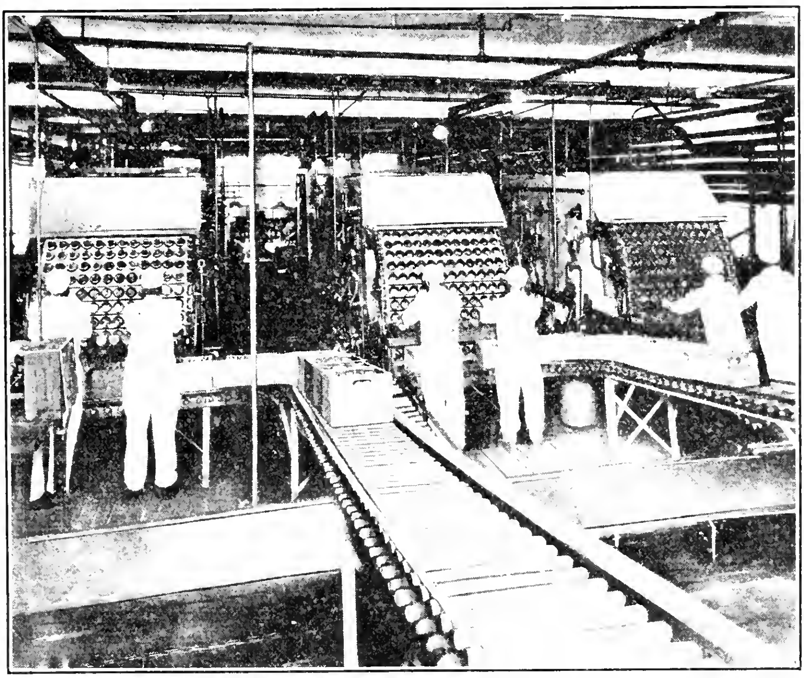

FIGURE 16.—Washing bottles where the direct system of washing and filling is used and where system 2 is used in checking in the routes. At eight plants using this combination an average of 8.1 routes was checked in per man-hour and 1,204 bottles washed per man-hour

Table 4 shows the importance of the system used in washing and filling the bottles. The average number of bottles washed per man-hour was 748.4 for the 97 plants using the indirect system, 1,251.9 for the 6 plants using the semidirect system, and 1,016.2 for the 68 plants using the direct system. The number of bottles filled per man-hour was 731.7, 902.5 and 1,392 respectively for the three systems, indirect, semidirect, and direct.

At many plants where the number of bottles washed per man-hour was small, the number filled per man-hour was great, and vice versa. The average number of bottles washed and filled per man-hour is,

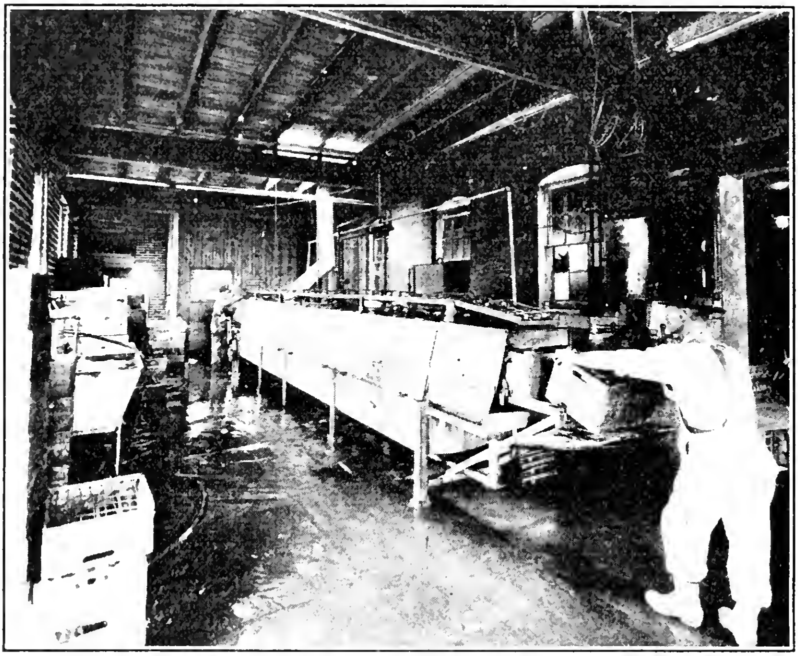

FIGURE 17.—Washing bottles at a plant using the indirect system of washing and filling

therefore, the best indication of the efficiency of the system. The number of bottles washed and filled per man-hour by the indirect, semidirect, and direct systems was 370, 525.4, and 586.8, respectively. The plants using the semidirect system washed, filled, and capped 42 per cent more bottles per man-hour than those using the indirect system. The percentage increase of the direct system over the indirect system was 58. Although no comparison of these systems has been made as to initial cost of machinery, cost of upkeep, or of steam and power required to operate the machines, these figures indicate a distinct advantage in favor of the direct system as far as labor is concerned. The trend at the present time is toward the use of this system.

TABLE 4.—*Comparison of direct, indirect, and semidirect systems of washing and filling bottles as to average time and labor requirements at 171 milk plants*

System	Number bottles handled daily	Plants	Washing bottles: Bottles per plant	Washing bottles: Men per plant	Washing bottles: Time required per plant: Hours[1]	Washing bottles: Time required per plant: Man-hours[2]	Washing bottles: Per hour	Washing bottles: Per man-hour
		Number	*Number*	*Number*			*Number* [1]	*Number* [2]
Indirect	5,000 or fewer	8	4, 148	1. 6	3. 9	6. 1	1, 070	684
	5,001 to 10,000	16	7, 231	2. 8	3. 5	10. 2	2, 040	707
	10,001 to 15,000	13	11, 545	3. 7	4. 6	17. 8	2, 502	648
	15,001 to 20,000	14	17, 893	3. 8	6. 6	26. 5	2, 708	675
	20,001 to 30,000	14	25, 258	4. 4	6. 4	32. 4	3, 964	780
	30,001 to 50,000	19	40, 223	5. 4	7. 2	45. 5	5, 578	884
	50,001 to 100,000	13	73, 527	12. 0	8. 0	105. 5	9, 138	697
Total or average		97	27, 043	4. 9	5. 9	36. 1	4, 594	748. 4
Semidirect	20,001 to 30,000	2	26, 667	2. 8	6. 3	23. 4	4, 267	1, 140
	30,001 to 50,000	4	38, 088	3. 3	8. 4	29. 4	4, 548	1, 297
Total or average		6	34, 281	3. 1	7. 7	27. 4	4, 471. 4	1, 251. 9
Direct	5,001 to 10,000	5	8, 625	1. 5	4. 3	7. 0	2, 006	1, 232
	10,001 to 15,000	9	12, 209	2. 0	5. 4	10. 7	2, 242	1, 139
	15,001 to 20,000	6	18, 323	3. 0	6. 6	19. 4	2, 783	944
	20,001 to 30,000	6	24, 728	3. 0	6. 8	20. 1	3, 663	1, 231
	30,001 to 50,000	19	39, 611	5. 1	7. 2	37. 4	5, 514	1, 059
	50,001 to 100,000	14	68, 309	9. 0	8. 4	74. 0	8, 118	923
	Over 100,000	9	126, 894	14. 4	8. 4	121. 6	15, 067	1, 043
Total or average		68	47, 975	6. 1	7. 1	47. 2	6, 788	1, 016. 2

System	Number bottles handled daily	Filling bottles: Bottles per plant	Filling bottles: Men per plant	Filling bottles: Time required per plant: Hours	Filling bottles: Time required per plant: Man-hours	Filling bottles: Per hour	Filling bottles: Per man-hour	Washing and filling bottles: Bottles per plant	Washing and filling bottles: Time required per plant	Washing and filling bottles: Per man-hour
		Number	*Number*			*Number*	*Number*	*Number*	*Man-hours*	*Number*
Indirect	5,000 or fewer	3, 883	2. 1	3. 3	7. 1	1, 172	550	4, 015	13. 1	306
	5,001 to 10,000	7, 160	2. 8	4. 1	11. 3	1, 762	636	7, 195	21. 5	335
	10,001 to 15,000	11, 357	3. 5	4. 7	15. 8	2, 440	720	11, 451	33. 6	341
	15,001 to 20,000	17, 476	4. 6	6. 2	27. 1	2, 817	644	17, 684	53. 6	330
	20,001 to 39,000	25, 105	5. 7	6. 5	36. 6	3, 867	686	25, 181	69. 0	365
	30,001 to 50,000	38, 539	7. 1	6. 8	45. 3	5, 667	850	39, 381	90. 8	434
	50,001 to 100,000	72, 337	12. 9	7. 7	100. 5	9, 451	719	72, 932	206. 1	354
Total or average		26, 412	5. 7	5. 8	36. 1	4, 590. 6	731. 7	26, 728	72. 2	370. 0
Semidirect	20,001 to 30,000	25, 167	5. 0	6. 3	31. 5	4, 027	799	25, 917	54. 9	472
	30,001 to 50,000	37, 732	5. 0	8. 0	40. 0	4, 717	943	37, 910	69. 4	546
Total or average		33, 544	5. 0	7. 4	37. 2	1, 522. 8	902. 5	33, 912	64. 6	525. 1
Direct	5,001 to 10,000	8, 604	1. 3	4. 0	4. 8	2, 151	1, 792	8, 614	11. 8	730
	10,001 to 15,000	12, 000	1. 3	6. 3	7. 1	1, 893	1, 688	12, 104	17. 8	679
	15,001 to 20,000	17, 956	2. 5	7. 2	17. 3	2, 506	1, 036	18, 140	36. 8	494
	20,001 to 30,000	24, 470	2. 6	7. 2	18. 6	3, 411	1, 317	24, 599	38. 7	636
	30,001 to 50,000	38, 834	3. 3	7. 3	22. 4	5, 339	1, 736	39, 222	59. 8	656
	50,001 to 100,000	67, 628	7. 0	8. 8	53. 9	7, 666	1, 251	67, 969	128. 0	531
	Over 100,000	125, 814	11. 1	9. 3	92. 4	13, 480	1, 362	126, 354	214. 0	590
Total or average		47, 390	4. 5	7. 5	34. 0	6, 334. 9	1, 392	47, 683	81. 3	586. 8

[1] No junk bottles included.
[2] Includes washing junk bottles.

RELATION BETWEEN NUMBER OF FLOORS USED AND MAN-HOUR REQUIREMENTS

The tendency at the present time is to confine plants to one or two floor levels. Many of the recently constructed plants have one story or one story with a mezzanine floor for the pasteurizing equipment, laboratory, etc. The machinery used in the direct system of washing and filling is well adapted to the 1-floor plant.

At many plants bottles are washed and filled on the street floor. At some plants, however, more than one floor is used for these operations. The bottles as they are received from the drivers may be sent to the basement or even to the second floor to be washed, and they are then sent up or down, as the case may be, to the street floor to be filled. In some cases bottles are filled on the second floor and are sent to the milk-storage room on the street floor. At all the plants the storage room is on the street floor.

Table 5 shows the number of man-hours required per 1,000 bottles washed and filled at 79 milk plants using either one floor or more than one floor for washing and filling the bottles.

The number of man-hours per 1,000 bottles washed and filled was 20 per cent greater for the plants using more than one floor than for the plants using only one floor.

Table 5.—*Man-hour requirements per 1,000 bottles washed and filled at 79 plants using either one floor or more than one floor for washing and filling bottles*

System	Plants using one floor		Plants using more than one floor		Difference between (A) and (B)
	Plants	Time required (A)	Plants	Time required (B)	
	Number	*Man-hours*	*Number*	*Man-hours*	*Per cent*
Direct	32	1.51	11	1.69	11.9
Semidirect	9	1.93			
Indirect	21	2.27	6	3.10	36.0
Total or average	62	1.83	17	2.19	20.0

Table 6 shows the relation between the number of floors used and the man-hour requirements for washing and filling bottles at 43 plants using the direct system. The number of man-hours required for the major [3] operations does not differ greatly at any of the plants. The number of man-hours required for the accessory [4] operations is greater at all the plants using more than one floor than at plants using only one floor, except at those plants handling 50,001 to 100,000 bottles daily. In this group slightly more man-hours per 1,000 bottles were required at the 1-floor plants than at the plants using more than one floor. At each of the latter plants only one man was required in getting the bottles to the washer. At the six plants in the group handling 50,001 to 100,000 bottles and using only one floor the number of man-hours required for miscellaneous operations was great, thus making the total amount of labor for accessory operations large. The principal reason for this was the large amount of labor used at these six plants for sorting and inspecting bottles both before and after they were filled.

[3] See footnote 2 under Table 6. [4] See footnote 1 under Table 6.

TABLE 6.—*Relation between the number of floors used and the man-hour requirements for washing and filling bottles at 43 plants using the direct system*

Bottles handled daily	Floors used	Plants	Bottles handled daily per plant	Man-hours required per 1,000 bottles for— Accessory operations [1]: Getting bottles to washer	Accessory operations [1]: Miscellaneous	Accessory operations [1]: Total	Major operations [2]	Total operations
		Number	*Number*					
20,000 or fewer	1	9	12,553	0.38	0.10	0.48	1.04	1.52
	More than 1	1	11,908	.76	.38	1.14	1.14	2.28
20,001 to 50,000	1	15	32,818	.19	.14	.33	1.12	1.45
	More than 1	5	34,614	.31	.29	.60	1.00	1.60
50,001 to 100,000	1	6	69,073	.29	.45	.74	.99	1.73
	More than 1	2	57,740	.13	.51	.64	.96	1.60
100,001 or over	1	2	114,855	.11	.30	.41	.82	1.23
	More than 1	3	136,886	.25	.65	.90	.82	1.72
Total or average	1	32	39,044	.26	.20	.46	1.05	1.51
	More than 1	11	15,627	.30	.44	.74	.95	1.69

[1] Such as getting the bottles to the washers and fillers and transferring them from place to place.
[2] Such as feeding the washers and fillers and taking bottles away from the washers and fillers.

The direct system of washing and filling is well adapted to plants of one floor. Of the 43 plants using this system, only 11 used more than one floor.

Table 7 shows the relation between the number of floors used and the man-hour requirements for washing and filling bottles at 27 plants using the indirect system.

TABLE 7.—*Relation between the number of floors used and man-hour requirements for washing and filling bottles at 27 plants using the indirect system*

Number of bottles handled daily	Floors used	Plants	Bottles handled daily per plant	Man-hours required per 1,000 bottles for— Accessory operations [1]: Getting bottles to washer	Accessory operations [1]: Disposing of bottles from washer	Accessory operations [1]: Getting bottles to filler	Accessory operations [1]: Miscellaneous	Accessory operations [1]: Total	Major operations [2]	Total operations
		Number	*Number*							
20,000 or fewer	1	6	8,490	0.12	0.19	0.29	0.15	0.75	1.55	2.30
	More than 1	1	19,000	.34	.16	.34	.42	1.26	2.23	3.49
20,001 to 50,000	1	10	34,329	.18	.22	.24	.24	.88	1.23	2.11
	More than 1	4	36,522	.33	.30	.36	.76	1.75	1.36	3.11
50,001 to 100,000	1	5	75,701	.33	.25	.37	.60	1.55	1.03	2.58
	More than 1	1	75,000	.32	.21	.21	.22	.96	1.70	2.66
100,001 or over	1									
	More than 1									
Total or average	1	21	36,797	.20	.20	.29	.30	.99	1.28	2.27
	More than 1	6	40,014	.33	.26	.34	.61	1.54	1.56	3.10

[1] Such as getting the bottles to the washers and fillers and transferring them from place to place.
[2] Such as feeding the washers and fillers and taking bottles away from the washers and fillers.

For plants of all sizes the number of man-hours required per 1,000 bottles washed and filled was greater for those using more than one floor than for those using only one floor. The labor employed for accessory operations was greater for all plants using more than one floor than for those using only one floor, with the exception of the one plant in the group handling between 50,001 and 100,000 bottles. At this plant the extra labor used was for major operations, so that the total for all the operations was greater than for the 1-floor plants in the group.

The results shown in Tables 6 and 7 seem to indicate that as a rule, regardless of the system used or the size of the plant, more labor is required to wash and fill bottles where more than one floor is used than where only one floor is used. Often some extra labor is required in transferring the bottles from one floor to another, even when conveyor systems are used. For example, at one plant where the bottles were received on the second floor and washed on the first floor an extra man was required to keep them in line on the conveyor leading from the second floor to the washer on the first floor.

PASTEURIZING AND COOLING MILK, CLEANING EQUIPMENT, AND STACKING BOTTLED MILK IN STORAGE ROOM

Table 8 shows the relation between the size of plant and labor requirements for pasteurizing and cooling the milk, for cleaning the equipment, and stacking bottled milk in the storage room at 112 plants. According to the table, labor for pasteurizing and cooling milk can be used more economically in large plants than in small ones. At least one man must be detailed to the pasteurizing department in plants of all sizes. Even in small plants this man can do little more than attend to the pasteurizing equipment during the operation. Since large plants usually require not more than two men, the quantity of milk handled per man in large plants is much greater than in small plants.

At small plants the man who operates the pasteurizer often does some cleaning during the last part of the run. This fact partly accounts for the comparatively small number of man-hours for cleaning charged to these plants, as shown by Table 8. Many large plants have found it desirable and economical to employ men to spend their entire time in cleaning the pasteurizing and cooling equipment. This system, however, would not be practical for small plants. When the total amount of labor for pasteurizing the milk and cleaning the equipment is considered there is not a great difference between the quantity of milk pasteurized per man-hour at the small plants and at the large ones.

TABLE 8.—*Relation between the size of plant and labor requirements for pasteurizing and cooling the milk, cleaning the equipment, and stacking the bottled milk in storage room at 112 plants*

Group	Milk handled (gallons)	Plants	Milk pasteurized and cooled per man-hour	Labor required per day for cleaning pasteurizing equipment	Milk pasteurized and cooled per man-hour (including cleaning equipment)	Bottles stacked in storage room per man-hour
		Number	*Gallons*	*Man-hours*	*Gallons*	*Number*
1	3,000 or less	21	439	3.7	246	1,907
2	3,001 to 5,000	22	690	5.0	341	2,152
3	5,001 to 10,000	38	982	9.3	434	2,346
4	10,001 to 15,000	17	1,290	17.3	176	2,238
5	Over 15,000	11	1,588	21.1	150	2,162

The number of bottles stacked in the storage room per man-hour is fairly uniform for plants of all sizes. Practically the same system is used at all plants, and one man can handle about the same number regardless of the size of the plant.

CHECKING OUT THE ROUTES

The time required to check out a given number of routes depends a good deal on the system used. In a study carried on at 93 milk plants the following 8 systems for checking out the routes were found: (1) Direct from the storage room through one door or chute; (2) use of barrel or warehouse trucks;[5] (3) direct from the storage room through two doors or chutes; (4) use of wheel platform or dolly trucks;[5] (5) use of lift trucks;[5] (6) direct from storage room through three doors or chutes; (7) direct from storage room through four or more doors or chutes; and (8) from seven or more loading points.

Table 9 shows the results of a study at 19 plants that checked out routes direct from the storage room through one door or chute. This system is employed usually only at small plants. At several of the plants studied only one man was used, and at only four plants were more than two men used.

TABLE 9.—*Labor and time required at 19 plants for checking out routes through one door or chute*

Plant No.	Routes			Men employed	Hours of work	Man-hours [1]	Routes per hour	Routes per man-hour [1]	Time required per route
	Wholesale	Retail	Total						
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Minutes*
1	0	8	8	1.0	1.5	1.5	5.3	5.3	11.3
2	0	9	9	3.0	1.0	3.0	9.0	3.0	6.7
3	2	8	10	1.0	2.5	2.5	4.0	4.0	15.0
4	0	10	10	1.0	1.0	1.0	10.0	10.0	6.0
5	1	10	11	2.0	1.5	3.0	7.3	3.7	8.2
6	2	16	18	2.0	2.0	4.0	9.0	4.5	6.7
7	1	21	22	2.0	3.0	6.0	7.3	3.7	8.2
8	0	23	23	2.0	2.0	4.0	11.5	5.7	5.2
9	0	24	24	1.0	3.0	3.0	8.0	8.0	7.5
10	0	26	26	2.0	1.5	3.0	17.3	8.7	3.5
11	5	22	27	2.0	3.5	7.0	7.7	3.9	7.8
12	3	25	28	1.0	5.5	5.5	5.1	5.1	11.8
13	0	28	28	2.0	2.0	4.0	14.0	7.0	4.3
14	1	27	28	2.0	1.5	3.0	18.7	9.3	3.2
15	0	32	32	3.0	4.0	12.0	8.0	2.7	7.5
16	6	32	38	2.0	3.0	6.0	12.7	6.3	4.7
17	5	36	41	2.0	3.5	7.0	11.7	5.9	5.1
18	0	48	48	3.0	3.0	9.0	16.0	5.3	3.8
19	6	42	48	3.0	3.0	9.0	16.0	5.3	3.8
Average	1.7	23.5	25.2	1.9	2.5	4.9	10.0	5.1	6.0

[1] Number of man-hours required for putting up orders is included.

Table 9 shows considerable variation in the time required to check out one wagon at the different plants. At plant 3, 15 minutes was required for each route, whereas at plant 14 only 3.2 minutes was required. At plant 3 one-fifth of the routes were wholesale, and only one man was used; whereas at plant 14 only 1 of the 28 routes was wholesale, and two men were used. When only one man

[5] A description of these trucks is given on p. 10.

is used, it is not possible to load out as fast as when two or more men are used. This system, however, is well adapted to small plants, and although the actual time required per route may be higher than with other systems, fewer men are used.

As a rule at plants using this system only one wagon could be loaded at a time, although at a few plants the conveyor from the storage room led to a platform alongside of which two or three wagons could be loaded simultaneously. This was true in the case of plants 18 and 19. More men were required where this was done, and such an arrangement was not always desirable.

Table 10 shows the results of studies at six plants checking out routes by the use of barrel or warehouse trucks. All these plants were located in New England, where this system was fairly common when the data were obtained. One of the reasons for the use of this system was the type of delivery wagon used in that section. At most of the plants studied, end-door wagons were used. These wagons had to be loaded at the rear instead of at the side. They had to be backed to the loading platform; and since it was usually desirable to put the full load on at one point, this type of wagon was not adaptable to the system of loading direct from the storage room through several chutes. When the latter system was used the route driver usually obtained the quarts of milk at one door, pints at another, and so on. In some plants neither conveyors, lift trucks, nor loading direct from the storage room could be employed because of the location of the storage room in respect to the loading platform, and at these plants a system such as this was necessary.

TABLE 10.—*Labor and time required at six plants for checking out routes by the use of barrel or warehouse trucks*

Plant No.	Routes			Men employed	Hours of work	Man-hours [1]	Routes per hour	Routes per man-hour [1]	Time required per route
	Wholesale	Retail	Total						
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Minutes*
1	6	32	38	3	3.0	21	12.7	1.8	4.7
2	19	29	48	6	7.0	42	6.9	1.1	8.7
3	20	50	70	8	4.5	36	15.6	1.9	3.8
4	0	42	42	4	5.0	20	8.4	2.1	7.1
5	19	50	69	8	4.5	36	15.3	1.9	3.9
6	19	42	61	7	6.0	42	10.2	1.5	5.9
Average	13.8	40.8	54.7	6	5.0	32.8	10.9	1.7	5.5

[1] Number of man-hours required for putting up orders is included.

At the plants using this system a considerable number of men were employed, the average being six per plant; at each of two plants eight men were used. The time required was also rather long, the average being five hours. The fact that many of the plants had a large proportion of wholesale routes partly accounts for the average number of routes loaded per hour being small.

Where several wagons can be loaded at one platform at a time and the plant is so laid out that a system of direct loading through three or more chutes is not possible, good results as to time may be obtained by the use of barrel or warehouse trucks. This is illustrated in the case of plant 5 where four or five wagons could be loaded at the same time.

With the use of barrel or warehouse trucks in checking out routes considerable extra labor is required to get the orders ready before the delivery wagons arrive. Where the plant is so arranged that several wagons can be loaded at the same time and the men come a little early and pull out several loads ahead, the actual loading time may be comparatively short. This extra labor, however, must be considered.

Table 11 shows the results of studies made at 24 plants checking out routes direct from the storage room through two doors or chutes. (Fig. 18.) A considerable variation was found in the results obtained both as to routes checked out per hour and per man-hour. At plant 15, for example, an average of 21.6 routes were checked out per hour, and 10.8 per man-hour; whereas at plant 16, which is of about the same size, only 14 and 4.7 routes were checked out per hour and per man-hour, respectively. The arrangement of the milk and cream in

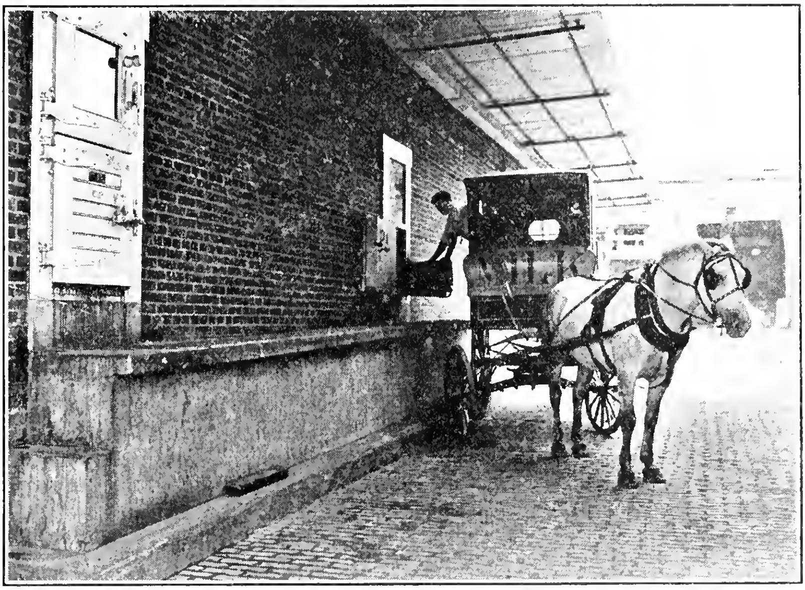

FIGURE 18.—Loading a delivery wagon at a plant checking out routes through two doors or chutes. (Only one chute was in use at the time the photograph was taken.) An average of 13.6 wagons per hour was loaded at 24 plants using this system, and the average time required to load one wagon varied from 2.7 to 7.9 minutes.

the storage room had much to do with the results. In some cases the bottles were so crowded that the men did not have enough room to work conveniently, whereas in other plants the bottles were arranged very conveniently so that the milk and cream could be quickly sent out on the wagons with a minimum of handling. The average number of routes at the plants in this group was 48.3, and the average time required to load out the routes at each plant was 3.6 hours, which indicates that this is a satisfactory system for plants of medium size. Two wagons were loaded out at the same time. One man usually put the bottles of milk out at one door while another man checked out the cream, etc., at the other door. The number of men used varied from two to five, indicating that labor was used more economically at some plants than at others. This was due to the more convenient arrangement of the storage room and conveyors.

TABLE 11.—*Labor and time required at 24 plants for checking out routes through two doors or chutes*

Plant No.	Routes			Men employed	Hours of work	Man-hours [1]	Routes per hour	Routes per man-hour [1]	Time required per route
	Wholesale	Retail	Total						
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Minutes*
1	3	17	20	2	2.0	4.0	10.0	5.0	6.0
2	5	16	21	2	2.0	4.0	10.5	5.3	5.7
3	0	23	23	2	2.5	5.0	9.2	4.6	6.5
4	0	25	25	2	3.0	6.0	8.3	4.2	7.2
5	0	33	33	2	2.5	5.0	13.2	6.6	4.5
6	0	34	34	2	4.5	13.0	7.6	2.6	7.9
7	0	35	35	2	3.0	6.0	11.7	5.8	5.1
8	0	36	36	3	3.0	9.0	12.0	4.0	5.0
9	0	40	40	2	2.0	8.0	20.0	5.0	3.0
10	0	42	42	2	3.5	7.0	12.0	6.0	5.0
11	2	40	42	2	5.0	10.0	8.4	4.2	7.1
12	2	43	45	3	3.5	14.5	12.9	3.1	4.7
13	20	29	49	2	5.0	10.0	9.8	4.9	6.1
14	14	38	52	3	5.0	23.0	10.4	2.3	5.8
15	3	51	54	2	2.5	5.0	21.6	10.8	2.8
16	6	50	56	3	4.0	12.0	11.0	4.7	4.3
17	10	48	58	5	4.5	22.5	12.9	2.6	4.7
18	3	58	61	4	3.0	12.0	20.3	5.1	3.0
19	0	62	62	3	4.75	14.3	13.1	4.3	4.6
20	15	48	63	4	4.0	16.0	15.8	3.9	3.8
21	7	62	69	4	4.0	16.0	17.3	4.3	3.5
22	4	68	72	5	4.0	20.0	18.0	3.6	3.3
23	0	76	76	4	4.0	16.0	19.0	4.8	3.2
24	4	86	90	4	4.0	16.0	22.5	5.6	2.7
Average	4.1	44.2	48.3	2.9	3.6	11.4	13.6	4.2	4.4

[1] Number of man-hours required for putting up orders is included.

Table 12 shows the results obtained at six plants checking out routes by wheel platform or dolly trucks. This was not a common system, as the number of plants in the group indicates. It was used at plants of all sizes, the number of routes per plant varying from 10 to 120. There was also a great variation in the number of men used, varying from 1 at plant 2 to 6 at plants 4 and 5. Primarily because of this difference in number of men used, the time required to check out one route varied from 2.5 minutes at plant 6 to 18.2 minutes at plant 3. At the larger plants using this system several routes could be checked out at the same time.

TABLE 12.—*Labor and time required at six plants for checking out routes by wheel platform or dolly trucks*

Plant No.	Routes			Men employed	Hours of work	Man-hours [1]	Routes per hour	Routes per man-hour [1]	Time required per route
	Wholesale	Retail	Total						
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Minutes*
1	0	10	10	2	2.5	5	4.0	2.0	15.0
2	2	10	12	1	2.0	4	6.0	3.0	10.0
3	7	6	13	2	4.0	8	3.3	1.6	18.2
4	4	65	69	6	4.0	30	17.3	2.3	3.5
5	6	82	88	6	4.0	24	22.0	3.6	2.7
6	21	99	120	4	5.0	30	24.0	4.0	2.5
Average	6.7	45.3	52	3.5	3.6	16.8	14.5	3.1	4.1

[1] Number of man-hours for putting up orders is included.

Table 13 shows the results obtained at 10 plants checking out routes by the use of lift trucks. At 7 of these plants the routes were principally retail, whereas the other 3 had a large proportion of wholesale routes. The variation in the size of the loads was one of the principal causes of the large variation in the number of routes checked out per hour and per man-hour. The time and labor required were naturally much greater for the plants having principally wholesale routes, as larger loads were carried.

At plants so arranged that several wagons could be loaded at the same time, a large number of routes were checked out per hour. This was the case at plant 6, where 31.3 retail routes were checked out per hour. Twelve men were used at this plant, however, and the number of routes checked out per man-hour was only 1.3. At plant 9, 25 routes were checked out at the rate of 12.5 per hour, which compares favorably with the other plants when it is considered that all the routes at plant 9 were wholesale. Ten men were used at this plant, however, so that although the number of routes checked out per hour was comparatively large, the number checked out per man-hour was small.

TABLE 13.—*Labor and time required at 10 plants for checking out routes by lift trucks*

PLANTS HAVING LARGE PROPORTION OF RETAIL ROUTES

Plant No.	Routes			Men employed	Hours of work	Man-hours [1]	Routes per hour	Routes per man-hour [1]	Time required per route
	Wholesale	Retail	Total						
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Minutes*
1	2	12	14	1	1.5	3.0	9.3	4.7	6.5
2	0	17	17	1	1.0	5.0	17.0	3.4	3.5
3	0	20	20	10	1.0	14.0	20.0	1.4	3.0
4	0	37	37	5	1.5	13.5	24.7	2.7	2.4
5	0	41	41	4	3.0	20.0	13.7	2.1	4.4
6	0	47	47	12	1.5	36.0	31.3	1.3	1.9
7	0	58	58	7	3.5	24.5	16.6	2.4	3.6
Average	0.3	33.1	33.4	5.7	1.9	16.6	18.0	2.0	3.3

PLANTS HAVING LARGE PROPORTION OF WHOLESALE ROUTES

Plant No.	Wholesale	Retail	Total	Men employed	Hours of work	Man-hours [1]	Routes per hour	Routes per man-hour [1]	Time required per route
8	15	0	15	3	3	13	5.0	1.2	12.0
9	25	0	25	10	2	22	12.5	1.1	4.8
10	26	11	37	11	6	66	6.2	.6	9.7
Average	22	3.7	25.7	8	3.7	33.7	7.0	.8	8.5

[1] Number of man-hours for putting up orders is included.

Table 14 shows the results obtained at 14 plants checking out routes direct from the storage rooms through three doors or chutes. Although there was not a great variation in the time required per route, there was a great variation in the number of routes checked out per man-hour. This was due to the different arrangements of the storage rooms and the different methods of getting the milk to the chutes, resulting in a larger number of men being required at some plants than at others. For example, at plants 5 and 8, which checked out an especially large number of routes per man-hour, the bottles in the storage room were so arranged that they could be sent out on the conveyors with very little handling and only four and five men respectively were used at these two plants. At plants

4, 9, 13, and 14, however, the arrangement was not so convenient, and much handling was required, especially at plants 9 and 13, where trucks were used to a considerable extent to get the cases of milk to the conveyors leading to the chutes. The number of men used at these plants was large. Furthermore, 3 man hours were required at plant 4 and 10.5 man hours at plant 9 to put up orders beforehand. The reason for the small number of routes checked out per man-hour at plant 7 was that 14 man-hours was used in putting up orders beforehand.

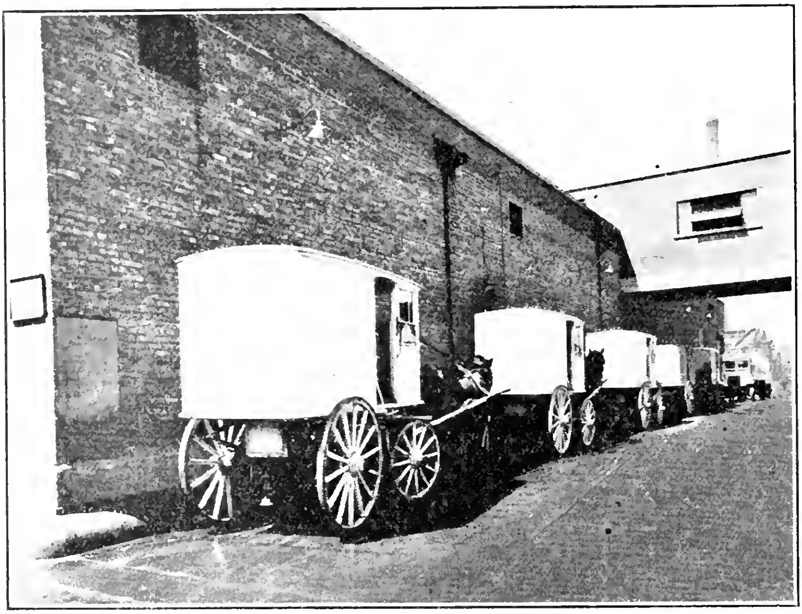

FIGURE 19. —Checking out routes at a plant using four or more doors or chutes. An average of 42.3 routes per hour and 4.4 routes per man-hour was checked out at 10 plants using this system

TABLE 14.—*Labor and time required at 14 plants for checking out routes through three doors or chutes*

Plant No.	Routes			Men employed	Hours of work	Man-hours [1]	Routes per hour	Routes per man-hour [1]	Time required per route
	Wholesale	Retail	Total						
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Minutes*
1	0	41	41	4	1.5	6.0	27.3	6.8	2.2
2	6	56	62	4	4.0	16.0	15.5	3.9	3.9
3	2	73	75	4	4.5	22.0	16.7	3.4	3.6
4	0	76	76	8	2.0	19.0	38.0	4.0	1.6
5	0	80	80	4	1.5	6.0	53.3	13.3	1.1
6	7	77	84	6	2.5	15.0	33.6	5.6	1.8
7	8	77	85	5	2.5	26.5	34.0	3.2	1.8
8	0	87	87	5	1.5	7.5	58.0	11.6	1.0
9	0	88	88	13	3.5	56.0	25.1	1.6	2.4
10	0	90	90	8	2.0	16.0	45.0	5.6	1.3
11	0	90	90	7	1.5	10.5	60.0	8.6	1.0
12	6	86	92	5	4.0	20.0	23.0	4.6	2.6
13	0	109	109	9	3.0	27.0	36.3	4.0	1.7
14	0	60	60	8	2.5	20.0	24.0	3.0	2.5
Average	2.1	77.9	79.9	6.4	2.6	19.1	30.7	4.2	2.0

[1] Number of man-hours for putting up orders is included.

Table 15 shows the results obtained at 10 plants checking out routes through four or more doors or chutes. (Figs. 19 and 20.) The driver usually received quarts of milk at one door, pints at another, and so on, although at some plants a full load was obtained at each door. In most cases no extra time was required to put up orders; the required quantity of goods was put out at the various doors as the wagons arrived. Side-door wagons are desirable for the use of this system. The time required to check out one route was fairly uniform for all the plants in this group, although there was considerable variation in the number of routes checked out per man-hour. At plant 2, which required more time than the average, no

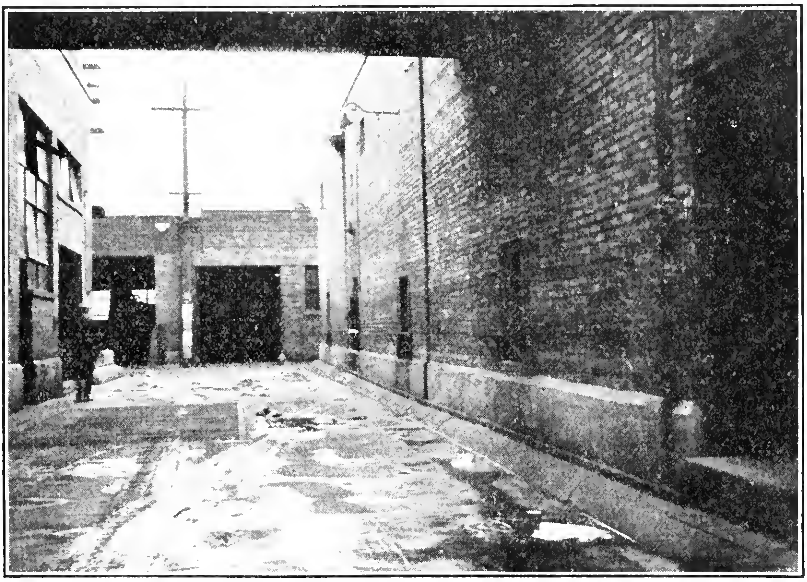

FIGURE 20.—A plant where routes are checked out through four loading doors

conveyors were used because the storage room was rather narrow. The men therefore had to transfer the cases of milk and cream by hand for a short distance to the various doors. Plant 4 had comparatively few routes checked out per man-hour, principally because of the fact that 16 man-hours was used for putting up orders beforehand. Especially good results were obtained at plants 6, 8, and 9. Each of these plants had six or more loading doors, and the result was that the wagons were loaded out very rapidly. Large plants can use to advantage the system of checking out routes through four or more doors or chutes. The average time required to check out one route at the 14 plants using this system was only 1.4 minutes, and at some plants routes were checked out in less than 1 minute.

TABLE 15.—*Labor and time required at 10 plants for checking out routes through four or more doors or chutes*

Plant No.	Routes: Wholesale	Routes: Retail	Routes: Total	Men employed	Hours of work	Man-hours [1]	Routes per hour	Routes per man-hour [1]	Time required per route
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Minutes*
1	1	76	80	6	2.5	15.0	32.0	5.3	1.9
2	2	88	90	8	3.5	28.0	25.7	3.2	2.3
3	0	102	102	7	3.0	29.0	34.0	3.5	1.8
4	[2] 31	83	114	8	2.5	36.0	45.6	3.2	1.3
5	6	118	124	11	5.0	55.0	24.8	2.3	2.4
6	0	144	144	6	2.0	12.0	72.0	12.0	.8
7	7	148	155	8	3.0	30.0	51.7	5.2	1.2
8	20	176	196	14	3.0	42.0	65.3	4.7	.9
9	0	180	180	6	2.5	15.0	72.0	12.0	.8
10	21	84	105	8	3.5	28.0	30.0	3.8	2.0
Average	9.1	119.9	129.0	8.2	3.1	29.0	42.3	4.4	1.1

[1] Number of man-hours for putting up orders is included.
[2] Many of these routes were mixed wholesale and retail.

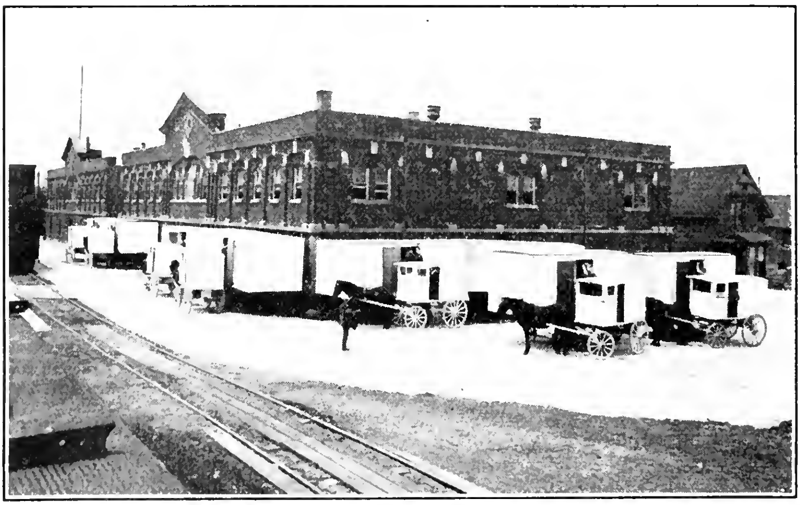

FIGURE 21.—Checking out routes at a plant using seven or more loading points. At seven plants using this system an average of 53.8 routes was checked out per hour

Table 16 shows the results obtained at seven plants checking out routes from seven or more loading points. (Fig. 21.) Usually where this system was used special milks, such as grade A, certified milk, and buttermilk, were loaded from trucks or trailers conveniently located so that the drivers could go from one to another in one continuous line. As a rule cream was checked out from a point on the platform, and the quarts and pints of regular milk were checked out from the storage room through two or three doors or chutes, although in some cases these were loaded from trailers also.

TABLE 16.—*Labor and time required at seven plants for checking out routes at seven or more loading points*

Plant No.	Routes			Men employed	Hours of work	Man-hours [1]	Routes per hour	Routes per man-hour [1]	Time required per route
	Wholesale	Retail	Total						
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Minutes*
1	0	120	120	11	3.00	33.0	40.0	3.6	1.5
2	0	126	126	12	3.00	36.0	42.0	3.5	1.4
3	0	140	140	12	3.00	36.0	46.7	3.9	1.3
4	0	162	162	14	3.25	45.5	49.8	3.6	1.2
5	0	173	173	12	3.00	36.0	57.7	4.8	1.0
6	0	190	190	14	3.00	47.0	63.3	4.0	.9
7	15	190	205	20	2.50	50.0	82.0	4.1	.7
Average	2.1	157.3	159.4	13.6	3.00	40.5	53.8	3.9	1.1

[1] Number of man-hours for putting up orders is included.

Although the number of routes checked out per man-hour at all the plants using this system was fairly uniform, there was a considerable variation in the number of routes checked out per hour. At the larger plants more men were used, but the time required per route was much less than at the smaller plants in the group. As a rule more loading points were used at the larger plants. At the three largest plants the routes were checked out at the rate of one per minute or less.

COMPARISON OF DIFFERENT SYSTEMS AS TO LABOR AND TIME REQUIRED

Table 17 shows a summary of the results obtained at 93 plants using the eight systems of checking out the routes. The systems in the table are arranged in the order of the number of routes checked out per hour. This arrangement is also in accordance with the average number of routes at the plants, except in the case of systems 2 and 5, indicating that as a rule the larger dealers have adopted systems which are the most economical as to the time required.

Although the plants using system 1 checked out the fewest routes per hour, few men were required; this resulted in the average number of routes loaded out per man-hour being greater than under any of the other systems. The time required to check out one route was longer under system 1 than under any of the other systems; but as time is not so important a factor at small plants as at large ones, this system is well adapted for that type of plant. Furthermore, where the storage room is so located that the wagons can drive up alongside it, this system is very convenient, as no other space in the plant is taken up in the loading operation and, except for sometimes a conveyor across or lengthwise of the storage room, no special equipment is required.

The plants using system 2 checked out the smallest number of routes per man-hour. While it might not be possible to load the wagons direct from the storage room at these plants, it might be possible to use lift trucks, as in system 5. In comparison with plants using system 2, those using system 5 checked out nearly twice as many routes per hour and slightly more per man-hour. While the lift-truck system requires added investment in platforms and trucks, this investment might be justified at some plants by the increase in the amount of work that could be done per hour and per man-hour. In some cases it might even be desirable to rearrange the plant so that either system 3 or 6 could be used.

TABLE 17.—*Comparison of different systems of checking out routes as to labor and time required*

Group	System used	Plants	Routes: Wholesale	Routes: Retail	Routes: Total	Men employed	Hours of work
		Number	*Number*	*Number*	*Number*	*Number*	*Number*
1	One chute direct to wagon	19	1.7	23.5	25.2	1.9	2.5
2	Barrel or warehouse trucks	6	13.8	40.8	54.7	6.0	5.0
3	Two chutes to wagon	24	4.1	44.2	48.3	2.9	3.6
4	Wheel platform and dolly trucks	6	6.7	45.3	52.0	3.5	3.6
5	Lift trucks	7	0.3	33.1	33.4	5.7	1.9
6	Three chutes to wagon	14	2.1	77.9	79.9	6.4	2.6
7	Four or more chutes to wagon	10	9.1	119.9	129.0	8.2	3.1
8	Loading from seven or more points	7	2.1	157.3	159.4	13.6	3.0

Group	System used	Man-hours [1]	Routes per hour	Routes per man-hour [2]		Time required per route: Minutes [3]	Time required per route: Minutes [4]
		Number	*Number*	*Number* [3]	*Number* [4]		
1	One chute direct to wagon	4.9	10.0	5.1	5.1	6.0	6.9
2	Barrel or warehouse trucks	32.8	10.9	1.7	1.8	5.5	5.7
3	Two chutes to wagon	11.4	13.6	4.2	4.5	4.4	4.8
4	Wheel platform and dolly trucks	16.8	14.5	3.1	3.8	4.1	8.7
5	Lift trucks	16.6	18.0	2.0	3.1	3.3	3.6
6	Three chutes to wagon	19.1	30.7	4.2	4.7	2.0	2.0
7	Four or more chutes to wagon	29.0	42.3	4.4	4.9	1.4	1.5
8	Loading from seven or more points	40.5	53.8	3.9	4.0	1.1	1.1

[1] Man-hours required for putting up orders is included.
[2] Man-hours required for putting up orders is not considered.
[3] Weighted average.
[4] Average of averages.

System 3 was the system most commonly used at the plants studied. An average of only 2.9 men was used at each plant, and an average of 4.2 routes was checked out per man-hour, which is a higher average than was checked out at the plants using most of the other systems. The only plants with a higher average were those using systems 1 and 7. A slightly longer time was required on an average to check out one route than was the case at the plants using wheel platform or dolly trucks or lift trucks, but the average number of routes loaded out per man-hour was much greater than at the plants using either of these two systems. Furthermore, with system 3 no investment in trucks is necessary, and where plants are so arranged that the wagons can be loaded direct from the storage room this system seems to be much more desirable than either system 4 or 5.

System 4 was not a common system, although it was in use at a few rather large plants. Only slightly better results as to number of routes checked out per hour were obtained at plants using this system than at plants using systems 1, 2, and 3, whereas the number of routes checked out per man-hour was smaller than at the plants using most of the other systems.

Although plants using system 5 ranked higher than systems 1, 2, 3, and 4 in the number of routes loaded per hour, they averaged 5.7 men, whereas those using system 3 averaged only 2.9 men and those using system 1 averaged only 1.9 men. The number of routes loaded out per man-hour was only 2 at plants in Group 5, as compared with 4.2 at the plants in Group 3 and 5.1 at plants in Group 1.

The use of lift trucks gives better results than the use of barrel or warehouse trucks, as is shown by the fact that the number of routes checked out per hour and per man-hour was greater for system 5 than for system 2. However, in respect to the average number of routes checked out per man-hour the plants using system 5 ranked lower than those using systems 1, 3, and 4 and only slightly higher than those using system 2. On account of the large number of men required where trucks are used, it appears that more efficient results can be obtained when the wagons can be loaded direct from the storage room through two or more doors. However, at plants so arranged that the wagons can not be loaded direct from the storage room, system 5 seems to be the most satisfactory one.

One advantage of the use of lift trucks and of wheel platform and dolly trucks over the conveyor systems is that mistakes in counting are less likely to occur. When conveyors or chutes direct to the wagon are used (systems 1, 3, 6, and 7) it is not uncommon for differences to arise between the driver and the checker as to the number of cases that have been sent through. When trucks are used, the cases can be counted by both the checker and the driver before they are removed.

The average time required to check out one route at the plants using system 6 was only 2 minutes, whereas the shortest time required for any of the first five systems was 3.3 minutes for system 5. More men are required where system 6 is used, for there must be at least one man at each of the three doors to handle the cases of milk, besides one or more checkers. Table 17 shows that more than twice as many men were employed at plants using system 6 as at those using system 3, where only two doors were used. For plants checking out more than 50 routes, however, system 6 would be more desirable than system 3 because of the extra time that would be required with the latter system.

As the number of loading doors or loading points increases (systems 7 and 8) more men are required, so that the number of wagons loaded per man-hour will not increase in the same ratio as the number of wagons loaded per hour. The time required per route was, of course, less the more doors were used. Thus system 7 with four or more doors or chutes checked out an average of 42.3 routes per hour as compared with 13.6 routes checked out with system 3 (2 doors or chutes), and 30.7 routes with system 6 (3 doors or chutes). In number of routes checked out per man-hour with these 3 systems, however, the difference was not so great, as shown in the table. The plants using system 8 checked out the greatest number of routes per hour, the average being nearly one per minute. Not only is time saved by the use of this system but where it is necessary to truck special milks from another plant or from the railroad station the transfer of the milk to the storage room is saved as well as space in the storage room. Since the greatest number of men are required where this system is used, the average number of routes checked out per man-hour is less than with some of the other systems. At the seven plants using this system an average of 13.6 men was used, and the average number of routes checked out per man-hour was only 3.9.

As a rule the greatest number of men is required to operate the systems which are most efficient as to time required per route. As the number of chutes or loading points are increased, the number of men must be correspondingly increased. It is desirable that all the routes be checked out in three or four hours, and large plants must use several chutes or loading points in order to get the routes out on time, even though more men are required.

NUMBER OF MEN REQUIRED TO OPERATE A MILK PLANT

The number of men required to operate a milk plant depends on other factors besides the plant arrangement and types of equipment, which have been discussed. Chief among these are the size of plant and the number of stories in the plant.

RELATION BETWEEN SIZE OF PLANT AND LABOR REQUIREMENTS

Table 18 shows the relation between the size of plant and the number of men required at 92 plants, grouped according to number of gallons of milk and cream handled daily. As a rule, there is an increase in the number of gallons handled per man as the size of the plant increases. In small plants it is usually necessary to shift a man from one job to another, whereas in large plants one man often is on the same operation for the full day. This specialization of labor naturally effects economies in operation. At large plants, however, on account of this very fact of specialization, more supervision is required, and more special and miscellaneous men are used, so that the difference in the number of gallons handled per man at the large and small plants is not so great as might be expected. This difference is somewhat greater, however, when bottled milk alone is considered.

TABLE 18.—*Relation between the size of plant and labor requirements*

Group No.	Plants	Milk and cream handled daily per plant			Total men per plant [1]	Milk and cream handled per man	
		Quantity	Average	Bottled		Total	Bottled
	Number	*Gallons*	*Gallons*	*Per cent*	*Number*	*Gallons*	*Gallons*
1	13	2,000 or less	1,407	81.0	6.8	208	169
2	21	2,001 to 5,000	3,308	88.2	15.3	216	194
3	34	5,001 to 10,000	7,342	85.1	34.5	213	181
4	9	10,001 to 15,000	11,504	82.0	46.0	249	205
5	8	15,001 to 20,000	17,393	87.0	78.6	221	192
6	7	Over 20,000	27,448	88.0	103.0	267	235

Group No.	Special help employed				Help employed per 1,000 gallons milk and cream handled				
	Relief men	Checkers	Engineers and maintenance men [2]	Miscellaneous men [3]	Total men	Relief men	Checkers	Engineers and maintenance men	Miscellaneous men
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
1	0.3	0.9	0.5	0.5	4.808	0.219	0.629	0.383	0.328
2	1.1	2.2	1.4	1.1	4.618	.317	.669	.425	.331
3	2.2	6.7	3.4	2.3	4.701	.305	.906	.457	.309
4	1.9	7.3	5.0	5.8	4.015	.164	.637	.434	.502
5	6.9	13.4	8.9	5.5	4.522	.395	.769	.510	.316
6	6.0	13.4	8.7	9.3	3.753	.219	.489	.318	.338

[1] Including all men whose time was chargeable to the market-milk department. If they were used in other departments also, time was prorated. Clerks and bookkeepers were not included.

[2] Employees who were engaged in the repair and upkeep of equipment and whose time was chargeable to the market-milk department.

[3] Such as foremen, janitors, and elevator men.

Table 18 shows two exceptions to the rule that the number of gallons of milk and cream handled per man increases as the size of the plant increases. These exceptions are the plants in Groups 3 and 5. They can in part be explained by the fact that there were no 1-story plants in Group 5 and only 6 out of a total of 34 in Group 3. As is shown on pages 37 and 38, less labor is usually required to operate 1-story plants.

The table shows no relation between the number of relief men used per 1,000 gallons handled and the size of the plant, as the number is dependent largely on the practices followed in the city where the milk plant is located. In some cities no relief men are required, as all the men work a full week of seven days. In others, the men work only six days per week so that an extra man is required for each six men. There is also very little relation between the size of plant and the number of checkers used per 1,000 gallons of milk and cream handled as this is determined primarily by the system of checking routes in and out. The table shows that, although the number of miscellaneous men employed increases with the size of the plant, the number of these men per 1,000 gallons of milk and cream handled is fairly uniform for plants of all sizes except Group 4, in which it is higher than in the other groups. The fact that this group contained only plants of more than one story is the principal reason for the large number of miscellaneous men.

RELATION BETWEEN NUMBER OF STORIES IN PLANT AND LABOR REQUIREMENTS

The number of men required to operate a milk plant seems to be affected to some extent at least by the number of stories in the plant. As a rule, fewer men are required in plants using only one story than in plants using several stories.

Table 19 shows the relation between the number of stories in the plant and the labor requirements.

More milk was handled per plant employee in the 1-story plants than in the 2-story plants, and with only two exceptions more was handled in the 2-story plants than in the plants of three or more stories. In Group 6 less milk was handled per man in the 2-story plants than in the plants of three or more stories. One of the reasons for this was that one of the 2-story plants was a grade A plant [6] and handled only 188 gallons of bottled milk per plant employee, which lowered the average for the group. The other exception was the one plant of three or more stories in Group 4. In this plant the milk was pasteurized on the second floor and was bottled on the first floor. The bottles were washed in the basement, but the bottle washer elevated the bottles to the first floor, where they were filled, thus eliminating the necessity of conveyors or elevators.

From the survey that was made it seems apparent that best results as to labor required are obtained where the bottle-washing and filling departments and the milk-storage room are on the street floor. The principal reason for this is that a minimum of handling and of supervision is required at this type of plant. Where the bottles are washed in the basement and the bottle washer delivers the bottles to the fillers on the street floor, nearly as good results are achieved.

[6] This plant, because it handled grade A milk, met special requirements of the city health officials.

TABLE 19.—*Relation between the number of stories and labor requirements in milk plants*

PLANTS HAVING ONE STORY

Group No.	Plants	Milk and cream handled per plant			Employees	Milk and cream handled per employee		
		Quantity	Average	Bottled		Total	Bottled	Exclusive of checkers[1]
	Number	*Gallons*	*Gals.*	*Per cent*	*Number*	*Gals.*	*Gals.*	*Gals.*
1	5	2,000 or less	1,314	83.7	5.8	227	190	263
2	10	2,001 to 5,000	3,152	88.9	11.0	287	255	341
3	6	5,001 to 10,000	7,570	90.1	26.2	289	261	361
4	2	10,001 to 15,000	10,975	84.5	30.0	366	309	422
5		15,001 to 20,000						
6	1	Over 20,000	21,000	82.0	67.0	313	257	344

PLANTS HAVING TWO STORIES

Group No.	Plants	Quantity	Average	Bottled	Employees	Total	Bottled	Exclusive of checkers
1	8	2,000 or less	1,466	79.6	7.1	199	158	228
2	11	2,001 to 5,000	3,631	85.7	19.0	189	164	220
3	23	5,001 to 10,000	7,103	84.9	34.4	206	175	252
4	6	10,001 to 15,000	11,742	80.6	52.5	224	180	263
5	4	15,001 to 20,000	16,875	83.7	57.3	295	247	343
6	3	Over 20,000	25,261	88.1	102.6	246	217	277

PLANTS HAVING THREE OR MORE STORIES

Group No.	Plants	Quantity	Average	Bottled	Employees	Total	Bottled	Exclusive of checkers
1		2,000 or less						
2		2,001 to 5,000						
3	5	5,001 to 10,000	8,169	82.7	45.0	182	150	235
4	1	10,001 to 15,000	11,150	88.0	41.0	272	239	372
5	4	15,001 to 20,000	17,910	89.3	100.0	179	160	220
6	3	Over 20,000	31,783	89.3	115.3	276	246	327

[1] At some plants the checkers are not included with the plant employees but with the delivery or sales employees.

COMPARISON OF THE AMOUNT OF LABOR USED IN PLANTS IN VARIOUS SECTIONS OF THE COUNTRY

More of the favorable features of milk-plant arrangement naturally are found in plants of some sections of the country than of others. Table 20 shows a comparison of the amount of labor used in plants grouped according to sections of the country. In the plants in the Chicago district relatively few men were used per 1,000 gallons handled. Inasmuch as higher wages were paid to plant employees in this district, however, than in most other districts, it was possible for the plants to employ more efficient men. The actual cost of operation of these plants per unit, therefore, may not have been less than the cost in other districts.

The plants in the Detroit district also used comparatively few men, except miscellaneous men. A large number of these were required, partly because several of the plants were of more than one story, one plant containing five stories, thus necessitating extra foremen, elevator men, conveyor men, etc.

The plants in the New York City district used a large number of checkers and relief men as compared with the number in the other groups. The men in most of these plants also worked on a basis of six days per week. Although the plants in this district had very efficient systems of checking the routes in and out as far as time required is concerned, they nevertheless used a large number of men in this work. The checkers performed no other work nor were any men transferred to this department from other departments during rush periods or emergencies as was sometimes done at plants in other sections. It was therefore necessary to have a full quota of men in this department at all times.

TABLE 20.—*Comparison of the amount of labor used at milk plants in different sections of the country*

Section of country	Plants	Milk and cream handled daily per plant	Help employed					Help employed per 1,000 gallons milk and cream handled				
			Total men	Relief men	Checkers	Engineers and maintenance men	Miscellaneous men	Total men	Relief men	Checkers	Engineers and maintenance men	Miscellaneous men
	Number	*Gallons*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
Chicago	24	8,852	31.8	3.9	4.4	2.4	1.8	3.588	0.437	0.497	0.273	0.205
Detroit	9	10,625	38.1	0.8	5.7	4.7	5.4	3.588	.073	.539	.439	.513
Northwest of Chicago	13	8,058	29.8	1.8	4.7	2.3	1.8	3.693	.219	.582	.286	.220
Philadelphia	9	9,482	35.7	0.3	5.8	3.6	3.8	3.763	.035	.610	.381	.399
Middle West (except Chicago and Detroit districts)	10	7,782	31.4	0.9	5.4	4.3	2.4	4.036	.116	.694	.553	.309
Baltimore and Washington	8	7,821	33.1	0.8	6.0	2.5	2.1	1.233	.096	.767	.320	.272
South Central	12	9,581	44.5	3.7	6.4	4.7	1.7	4.645	.383	.665	.487	.174
New York State (except New York City district)	5	3,416	17.4	1.4	3.0	2.3	0.8	5.088	.409	.877	.673	.234
New York City	9	16,767	89.7	9.4	17.6	7.8	4.9	5.355	.563	1.047	.464	.292
Southern	16	3,211	17.5	0.5	2.5	2.1	1.0	5.451	.152	.771	.666	.296
New England	10	6,611	38.3	2.1	6.6	3.9	3.3	5.794	.318	.999	.583	.499

The large number of checkers per 1,000 gallons handled at the plants in the New England, New York State, and southern districts was due to the comparatively inefficient systems used at some of these plants for checking the routes in and out. Some of these plants were quite small. The fact that many of the plants in New England were more than two stories high contributed to the comparatively large number of miscellaneous men required. This was also true in the case of the plants in the New York City districts.

It will be noted that the plants in the southern and New England districts used comparatively large numbers of men per 1,000 gallons handled in most departments. At many of the plants studied in these sections comparatively inefficient systems in respect to labor requirements were used for many of the operations, such as receiving the milk and checking the routes in and out. It should be noted that the average size of the plants studied in these sections was small, which fact tended to increase the average amount of labor required per unit for the plants in these groups.

SUMMARY AND CONCLUSIONS

Milk-plant operators should study their labor costs with a view to reducing them where possible.

Less labor is required for receiving and weighing milk at plants where the dump tank is near the receiving-room door or where conveyors are used than where the cans of milk are rolled or trucked in from the receiving platform.

Where milk is received from tank trucks or tank cars the labor required for receiving the milk is much less than where the milk is received in cans.

At the particular plants studied, where the milk was received in cans directly from the cars considerable labor was required because of the difficulty of effecting efficient arrangements for receiving the milk at these plants.

Less labor is required for checking in the routes at plants where conveyors are used than at plants where trucks of various kinds are used.

The operations of washing and filling bottles require nearly 50 per cent of the labor used for the principal operations in a milk plant.

The per unit labor requirements for washing and filling the bottles depend more on the system used than on the size of the plant.

The direct system of washing and filling bottles requires much less labor than does the indirect system.

Less labor is required for washing and filling bottles where the operations are performed on one floor than where two or more floors are used.

The quantity of milk pasteurized and cooled per man hour is much less at small plants than at large plants. This difference is not so great, however, when the labor for cleaning the equipment is included.

The number of bottles stacked in the milk-storage room per man-hour is fairly uniform for plants of all sizes.

The time and labor required to check out routes depend on the system used. Large plants require a system which permits many routes to be checked out in a short time.

The greatest number of routes are checked out per hour at plants where several loading points are used or where the wagons are loaded direct from the storage room through four or more small doors or chutes.

The number of routes checked out per man-hour does not vary greatly with the number of chutes used, since the more chutes used the greater the number of men required.

As a rule, trucks of various kinds are less economical as to labor required for checking out routes than is loading the wagons directly from the storage room through small doors or chutes.

An advantage of the use of trucks as compared with loading the wagons direct through chutes or from conveyors is that a more accurate check on the quantity of goods delivered to the driver is possible and that there is less likelihood of dispute as to the count.

Since it is necessary to check the routes in and out within a limited time the large plants as a rule have adopted the more efficient systems in respect to time required. The man-hour requirements per route checked in or out, however, are not always lower at the large plants.

As a rule, the number of gallons handled per plant employee is greater in large plants than in small ones.

The total number of men required is greater in plants of more than one story than in 1-story plants of similar capacities.

The number of gallons of milk handled per plant employee varies considerably in different sections of the country, in a large degree at least, because of the different plant arrangements and systems used.

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LIFE HISTORY OF THE ORIENTAL PEACH MOTH[1] IN GEORGIA

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INTRODUCTION

The first record of the oriental peach moth in the Southern States was from Valdosta, Ga., in the fall of 1923. Adults were reared from larvae found in peach twigs from the home orchard of R. M. Shaw of that city. Valdosta is south of the Georgia peach belt, and very few peaches are grown in that locality. During the summer of the same year suspicious injury was observed on several peach trees in the town of Fort Valley, Ga., which is in the center of the peach belt, but no larvae were taken for determination. During the spring of 1924 a number of larvae were collected in twigs from these same peach trees in Fort Valley, and they were determined as *Laspeyresia molesta* Busck. It is quite probable that the insect occurred at Fort Valley in 1923, the year it was first recorded in the South. It is now known to occur in practically all of the Southern States.

It is believed that the insect may have been brought into the South in infested apples. The first *L. molesta* larva collected in the Georgia peach belt was taken from a peach tree in the rear of a grocery store. It was learned that decayed apples were sometimes thrown out in the rear of that store. An adult *L. molesta* was reared from a larva in an apple that was purchased at that place. The barrel from which it came showed that the apple was shipped from a locality in the North where the insect was known to occur. Shipments of apples had been made from there to a produce dealer in

[1] *Laspeyresia molesta* Busck; order Lepidoptera, family Tortricidae.
[2] C. H. Alden, formerly of this bureau, assisted in taking the life-history records that are embodied in this report.

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Macon, Ga., and then were jobbed to merchants in a number of localities in the State. In nearly every locality in the South where the insect is known to occur the first infestation was confined to trees within or very near to the city or town limits.

Since a survey in 1924 showed that the insect was generally distributed throughout the South, and since it had caused considerable losses to peach growers in the Middle and North Atlantic States, where it had been established for some 10 years, it was deemed advisable to undertake a rather thorough-going life-history study of the insect in the South, so that its life history under southern conditions would be known in case the enforcement of control measures ever became necessary. Consequently the life history of the oriental peach moth was studied at Fort Valley, Ga., during 1925 and 1926, and this bulletin gives a report of that work.

LIFE-HISTORY STUDIES OF THE ORIENTAL PEACH MOTH IN 1925 AND 1926

MATERIAL USED

Wintering larvae for the life-history work in 1925 were obtained from material collected at Fort Valley, Ga., during the fall of 1924, from material sent to Fort Valley from other States during that fall, and from larvae hibernating in basket liners of corrugated paper sent to the writers in the spring of 1925 by E. N. Cory, of the University of Maryland. At the close of the insect season of 1925 there was an abundant supply of oriental peach moth larvae on hand with which to start the studies of 1926. In 1925 six generations and a partial seventh were reared in the insectary at Fort Valley. In 1926 five generations and a partial sixth were reared in the insectary.

OVIPOSITION

Oviposition records were obtained by caging a known number of female moths with males, and allowing them to oviposit on peach leaves. The eggs were counted at the end of each 24-hour period and transferred to incubation cages. During the season of 1925 oviposition records were taken on 1,287 females, with which were confined 1,451 males. A total of 52,723 eggs from those females was counted during the season. The average number of eggs deposited per female (all generations combined) was 41. Table 1 gives the period of oviposition of each brood in 1925 and the average number of eggs deposited per female.

TABLE 1.—*Period of oviposition of each brood of the oriental peach moth and average number of eggs deposited per female, Fort Valley, Ga., 1925*

Brood of moths	Number of moths		Date of—		Total number of eggs deposited	Average number of eggs per female
	Male	Female	First oviposition	Last oviposition		
Spring	58	34	Apr. 16	May 6	385	11.3
First	85	103	Apr. 29	June 9	658	6.4
Second	252	189	June 1	July 5	3,188	16.9
Third	380	287	June 28	Aug. 9	8,759	30.5
Fourth	311	352	July 10	Sept. 7	22,133	62.9
Fifth	210	230	Aug. 19	Oct. 10	11,493	50.0
Sixth	95	92	Sept. 19	Oct. 11	6,107	66.4
Total or average	1,151	1,287			52,723	41.0

The average number of eggs per female of the last three generations in 1925 was much higher than the average number per female of the first four generations.

During the 1926 season oviposition records were taken on 524 females, with which were confined 479 males. A total of 16,869 eggs from those females was counted during the season. The average number of eggs deposited per female (all generations combined) was 32.2. Table 2 gives the period of oviposition of each brood in 1926 and the average number of eggs deposited per female.

TABLE 2.—*Period of oviposition of each brood of the oriental peach moth and average number of eggs deposited per female, Fort Valley, Ga., 1926*

Brood	Number of moths		Date of—		Total number of eggs deposited	Average number of eggs per female	Average number of days—			
	Male	Female	First oviposition	Last oviposition			Before oviposition	From emergence to maximum oviposition	Of oviposition	From emergence to last oviposition
Spring	199	225	Apr. 7	June 1	2,164	9.6	3.6	4.9	6.8	9.4
First	74	78	May 23	July 2	4,033	51.7	1.9	4.0	9.3	10.2
Second	65	69	June 21	Aug. 1	3,079	44.6	2.3	4.2	8.4	9.6
Third	70	79	July 23	Sept. 1	3,433	43.5	2.0	4.4	7.8	8.8
Fourth	64	66	Aug. 17	Sept. 27	3,755	56.9	1.8	3.1	7.0	7.8
Fifth	7	7	Sept. 20	Oct. 5	405	57.9	2.8	4.4	6.8	8.6
Total or average	479	524			16,869	32.2				

Temperatures above 100° or below 65° F. greatly reduced the number of eggs laid. Maximum egg deposition took place upon days with an average temperature of from 80° to 85° and with a daily range of from 70° to 95°.

INCUBATION

The eggs laid upon the sides of the glass oviposition cages were counted and then destroyed. Those laid upon leaves were counted, placed between two strips of wire screening, and observed once daily until hatched. Incubation records were taken on a total of 16,081 eggs during the season of 1925. Table 3 gives the average, maximum, and minimum periods of incubation for eggs of each generation in 1925.

TABLE 3.—*Length of incubation period of eggs of each generation of the oriental peach moth at Fort Valley, Ga., in 1925*

Brood	Number of eggs under observation	Length of incubation period		
		Average	Maximum	Minimum
		Days	*Days*	*Days*
First	243	4.3	7	3
Second	364	4.3	7	3
Third	2,010	3.3	4	3
Fourth	4,868	3.2	4	3
Fifth	3,726	3.4	4	3
Sixth	3,317	3.5	4	3
Seventh	1,553	4.0	5	3

In 1926 incubation records were taken on a total of 5,947 eggs. Table 4 gives the average, maximum, and minimum periods of incubation for eggs of each generation in 1926.

TABLE 4.—*Length of incubation period of eggs of the oriental peach moth at Fort Valley, Ga., in 1926*

Brood	Number of eggs under observation	Length of incubation period		
		Average	Maximum	Minimum
		Days	*Days*	*Days*
First	1, 017	5. 7	9	3
Second	1, 420	3. 7	5	3
Third	1, 238	3. 7	4	3
Fourth	1, 684	3. 4	4	3
Fifth	1, 106	3. 7	4	3
Sixth	82	4. 2	5	4

LARVAL STAGE

LARVAL FEEDING PERIOD

The stock-jar method was used for the determination of the feedings period. Where the larvae were reared in cut twigs some difficulty was experienced in keeping the twigs from wilting. It was found necessary to supply fresh water daily and to replace them occasionally with fresh twigs in order that the larvae might reach maturity in a healthy condition. Much less difficulty was experienced when the larvae were bred in peach fruit, although occasionally the peaches were so serverely attacked by a rhizopus rot that the larvae were apparently unable to utilize them as food. The length of time from the date the larvae hatched until they entered a pupation stick to spin a cocoon was taken as the larval feeding period.

Records on the feeding period of 5,017 larvae were taken during the season of 1925; 437 of these were reared in peach twigs and 4,580 were reared in peach fruit. Table 5 gives the average, maximum, and minimum larval feeding periods for each brood during 1925.

TABLE 5.—*Length of feeding period of each brood of larvae of the oriental peach moth at Fort Valley, Ga., in 1925*

Brood	Number of larvae		Length of larval feeding period					
			In twigs			In fruit		
	In twigs	In fruit	Average	Maximum	Minimum	Average	Maximum	Minimum
			Days	*Days*	*Days*	*Days*	*Days*	*Days*
First	10	86	21. 0	28	16	16. 3	25	10
Second	50	93	10. 5	17	6	11. 3	24	8
Third	293	457	8. 4	14	7	10. 3	15	7
Fourth	73	1, 125	9. 1	16	5	12. 0	17	8
Fifth	11	1, 216	11. 2	17	6	11. 4	20	7
Sixth		1, 141				14. 7	41	7
Seventh		462				19. 2	39	11

During the season of 1926 larval feeding records were taken on 1,938 individuals. The stock-jar method was used, as in 1925, and all larvae were reared in fruit. Table 6 gives the average, maximum, and minimum larval feeding periods for each of the broods of 1926.

TABLE 6.—*Length of feeding period of each brood of larvae of the oriental peach moth at Fort Valley, Ga., in 1926*

Brood	Number of larvae	Length of larval feeding period in fruit		
		Average	Maximum	Minimum
		Days	*Days*	*Days*
First	362	13.7	23	9
Second	507	11.1	18	7
Third	430	10.8	21	7
Fourth	360	10.6	22	7
Fifth	268	12.9	26	6
Sixth	11	16.5	21	14

COCOONING PERIOD

As the larvae entered the pupation sticks after the end of the feeding period, they were given numbers and then examined daily till pupation occurred. This period from the time they entered the sticks until pupation is designated as the cocooning period, regardless of whether cocoons were spun or not. The great majority of larvae spun cocoons the same day they entered the sticks, a few delayed several days, and a very few pupated without spinning cocoons. A very small proportion of the overwintering larvae passed the winter in pupation sticks and pupated in the spring without ever having spun a cocoon.

Tables 7 and 8 give the length of the cocooning period of larvae during the seasons of 1925 and 1926 at Fort Valley, Ga., and also the total length of the larval stage of each brood (larval feeding and cocooning periods combined).

TABLE 7.—*Length of larval feeding period and total length of larval stage of each brood of the oriental peach moth, Fort Valley, Ga., 1925*

Brood	Average length of larval feeding period—		Average length of cocooning period (from end of feeding period to time of pupation)	Total average length of larval stage [1]—	
	In twigs	In fruit		In twigs	In fruit
	Days	*Days*	*Days*	*Days*	*Days*
First	21.0	16.3	[2] 8.5	29.5	24.8
Second	10.5	11.3	3.1	13.6	14.4
Third	8.4	10.3	2.8	11.2	13.1
Fourth	9.4	12.0	2.9	12.3	14.9
Fifth	11.2	11.2 [3] 12.9	3.0	14.2	14.2
Sixth		10.9 [3] 17.1	2.6		13.5
Seventh		[3] 19.2			

[1] Larval feeding and cocooning periods.
[2] The cocooning periods of some of these individuals were abnormal, as 1 took 41 days, 1 took 34 days, 4 took 32 days, 1 took 31 days, 2 took 28 days, 3 took 25 days, 2 took 23 days, 1 took 21 days, 1 took 19 days, and 1 took 18 days.
[3] Hibernating larvae.

TABLE 8.—*Length of larval feeding period and total length of larval stage of each brood of the oriental peach moth, Fort Valley, Ga., 1926*

Brood	Average length of larval feeding period	Average length of cocooning period (from end of feeding period to time of pupation)	Total average length of larval stage [1]
	Days	*Days*	*Days*
First	13.7	3.8	17.5
Second	11.1	2.9	14.1
Third	10.8	2.7	13.5
Fourth	10.3 [2] 12.6	2.5	12.8
Fifth	11.1 [2] 13.6	2.7	13.8
Sixth	[2] 16.5		

[1] Larval feeding and cocooning periods. [2] Hibernating larvae.

HIBERNATION OF LARVAE

After the completion of the larval feeding period, larvae entering the pupation sticks were given numbers and examined daily for pupation until cold weather had stopped transformation. The hibernating larvae were then examined approximately every two weeks during cold weather and once a week during warmer weather until spring. They were then examined daily. The pupation sticks containing the overwintering larvae were kept in glass jars in a screened insectary with a wooden roof.

Newly hatched larvae appeared in the field in the spring of 1925 about two weeks earlier than in the insectary. This was believed to be due either to lack of sunshine or to an insufficient supply of hibernating larvae in the insectary to represent accurately the field conditions.

In the fall of 1925 larvae were also placed in hibernation in a cage with screened sides and top. This cage was situated in the open, where the sun could reach it from all sides. In 1926 the first male moth in this cage emerged April 6, and the first from the insectary material, March 28. The first female moth in the cage emerged April 4, and the first in the insectary, April 7. The first eggs of the outdoor moths were laid April 7 and the first eggs of the insectary moths, April 9.

Very close agreement between insectary and outdoor-cage records was evident in 1926. It therefore seems possible that the differences noted the previous season were due to the small number of individuals under observation in the insectary. On the other hand, the earliest larvae noted in the field in 1925 might have been hatched from eggs deposited by moths which emerged very early because the overwintering larvae had hibernated in a position exceptionally favorable for early spring emergence.

In 1925, 12.1 per cent of the larvae of the fifth brood in the insectary, 64.6 per cent of the sixth, and 100 per cent of the seventh brood entered hibernation, there being seven broods that year. Table 9 gives the period of hibernation of these three broods of larvae that passed through the winter of 1925–26, and the date the first and last larva of each brood entered hibernation.

TABLE 9.—*Length of hibernation period of three broods of larvae of the oriental peach moth that passed through the winter of 1925–26 at Fort Valley, Ga., and the dates the first and last larva of each brood entered hibernation*

Brood of larvae (1925) [1]	Date first larva entered hibernation	Date last larva entered hibernation	Larvae surviving the winter	Proportion of 1926 spring-brood pupae derived from different broods of larvae of 1925	Length of hibernating period (from time of entering pupation sticks until pupation)		
					Average	Maximum	Minimum
	1925	1925	*Number*	*Per cent*	*Days*	*Days*	*Days*
Fifth	Aug. 26	Sept. 23	83	7.8	200.2	236	164
Sixth	Sept. 6	Nov. 19	598	56.3	181.1	232	140
Seventh	Sept. 5	Nov. 21	381	35.9	174.3	254	131

[1] Fourth-brood larvae existed when the Elberta peaches were being picked. The Elberta is the last commercial variety to ripen in Georgia. No fourth-brood larvae hibernated in 1925.

Table 10 gives the percentage of broods of larvae of 1925 entering hibernation, and the percentage of mortality of each brood during the winter of 1925–26. These data are derived from material which hibernated in the insectary and therefore do not accurately represent the mortality which occurred in the field.

TABLE 10.—*Percentage of broods of oriental peach-moth larvae of 1925 entering hibernation and percentage of mortality of each brood during the winter of 1925–26 in the insectary at Fort Valley, Ga.*

Brood of larvae (1925)[1]	Larvae under observation	Larvae that entered hibernation		Hibernating larvae that died during winter of 1925–26	
	Number	*Number*	*Per cent*	*Number*	*Per cent*
Fifth	1,371	166	12.1	69	41.6
Sixth	1,159	749	64.6	86	11.5
Seventh	413	413	100.0	32	7.7
Total or average	2,943	1,328	45.1	187	14.1

[1] One larva of the fourth generation started to hibernate, but died late in the fall of 1925.

In 1926, 11.8 per cent of the fourth, 86.7 per cent of the fifth, and 100 per cent of the sixth broods of larvae entered hibernation, there being six broods that year. Table 11 gives the dates the first and last larva of each brood entered hibernation in 1926, and the percentage of each brood that entered hibernation.

TABLE 11.—*Dates on which the first and last larva of each brood of the oriental peach moth entered hibernation in 1926 and percentage of each brood entering hibernation, Fort Valley, Ga.*

Brood of larvae (1926)	Date first larva entered hibernation	Date last larva entered hibernation	Larvae under observation	Larvae that entered hibernation	
			Number	*Number*	*Per cent*
Fourth	Aug. 27	Sept. 24	458	54	11.8
Fifth	Sept. 7	Oct. 28	271	235	86.7
Sixth	Oct. 12	...do....	12	12	100.0

PUPAL PERIOD

Observations on pupation were made daily by examining the larvae within the cocooning sticks. During the season of 1925 pupation records were taken on 3,676 individuals. The spring brood began to pupate on February 25. Table 12 gives the first and last pupation dates for each brood and the average, maximum, and minimum lengths of the pupal period for each brood.

TABLE 12.—*First and last pupation dates for each brood of the oriental peach moth and length of pupal period for each brood, Fort Valley, Ga., 1925*

Brood	Date of first pupation	Date of last pupation	Pupae under observation	Pupal period		
				Average	Maximum	Minimum
			Number	*Days*	*Days*	*Days*
Spring [1]	Feb. 25	Apr. 16	42	13.3	28	8
First [2]	Apr. 19	May 22	119	11.0	20	7
First [1]	May 6	June 16	73	11.4	35	6
Second [2]	May 10	June 23	260	9.4	13	5
Second [1]	May 18	June 21	129	8.8	12	4
Third [2]	May 12	July 6	131	8.0	13	5
Third [1]	June 17	July 23	649	8.4	17	5
Fourth [1]	July 12	Aug. 28	1,076	8.4	19	4
Fifth [1]	Aug. 5	Sept. 23	885	8.2	18	4
Sixth [1]	Sept. 6	Oct. 13	312	8.3	24	5

[1] Reared in insectary. Part of the spring-brood material was sent to Fort Valley from Maryland. Some of the first-brood larvae were reared in peach twigs, hence the late pupation. No larvae of the seventh generation pupated in the fall of 1925.
[2] From larvae collected in the field.

During the season of 1926 pupation records were taken on 2,536 individuals. The spring brood began to pupate on February 24, one day earlier than the first pupation record in 1925. However, one less generation occurred in 1926 as a result of the long pupation period of the spring brood and the lower September temperatures. Table 13 gives the first and last pupation dates for each brood and the average, maximum, and minimum length of the pupal period for each brood.

TABLE 13.—*First and last pupation dates for each brood of the oriental peach moth and length of pupal period for each brood in the insectary, Fort Valley, Ga., 1926*

Brood	Date of first pupation	Date of last pupation	Pupae under observation	Pupal period		
				Average	Maximum	Minimum
			Number	*Days*	*Days*	*Days*
Spring	Feb. 24	May 29	986	18.7	50	6
First	May 8	June 18	340	9.7	15	7
Second	June 10	July 22	478	9.3	13	4
Third	July 9	Aug. 23	414	8.6	17	6
Fourth	Aug. 7	Sept. 14	287	8.1	12	5
Fifth	Sept. 2	Sept. 20	31	8.8	12	6

MOTH EMERGENCE

In 1925 the first moth of the spring brood emerged on March 8 and the last moth emerged April 28. Moths of the first brood began to emerge April 28 and continued until July 8, the late-emerging moths being from larvae sent from Maryland. The second-generation moths began to emerge May 21 and continued emerging until July 8. Moths of the third generation started to emerge June 20 and continued until August 2. The fourth-generation moths started to emerge July 20 and continued until September 4. Those of the fifth generation began to emerge August 12 and continued until October 14, and those of the sixth generation emerged during the period from September 15 to October 25.

In 1926 the first moth of the spring brood did not emerge until March 28, and the last moth of that brood emerged June 8. Moths of the first brood began to emerge May 19 and continued emerging until June 29. Second-generation moths began to emerge June 18 and continued until August 1. Moths of the third generation started to emerge July 17 and continued until August 31. Fourth-generation moths emerged during the period from August 14 to September 23. A single moth (female) of the fourth generation emerged November 5, which is the latest moth-emergence record for this latitude. Fifth-generation moths emerged during the period from September 10 to September 27.

In all, 3,754 moths were reared during the season of 1925; 101 of these were of the spring brood, 101 of the first generation, 129 of the second generation, 723 of the third generation, 1,251 of the fourth generation, 1,081 of the fifth generation, and 368 of the sixth generation. The peak of emergence of each brood of moths was as follows: Spring brood, April 25; first brood, May 22; second brood, June 13; third brood, July 24; fourth brood, August 10; fifth brood, August 31; sixth brood, September 21. The daily rate of emergence of moths during the season of 1925 is shown in graphic form in Figure 1.

Altogether, 2,960 moths were reared during the season of 1926; 991 of these were of the spring brood, 414 of the first generation, 589 of the second generation, 541 of the third generation, 391 of the fourth generation, and 34 of the fifth generation. The peak of emergence of each brood of moths was as follows: Spring brood, April 26; first brood, June 11; second brood, July 2; third brood, August 2; fourth brood, August 31; fifth brood, September 20. The daily rate of emergence of moths during the season of 1926 is shown in graphic form in Figure 2.

LENGTH OF LIFE OF MOTHS

During 1925 daily records were kept on the length of life of 1,406 male and 1,243 female oriental peach moths. The males lived an average of 9.9 days and the females an average of 10.6 days. Table 14 gives the average, maximum, and minimum length of life of moths of each generation in 1925.

TABLE 14.—*Length of life of male and female oriental peach moths at Fort Valley, Ga., during the season of 1925*

Brood	Male moths				Female moths			
	Number	Length of life			Number	Length of life		
		Average	Maximum	Minimum		Average	Maximum	Minimum
		Days	*Days*	*Days*		*Days*	*Days*	*Days*
Spring	58	11.1	24	1	32	13.4	20	1
First	76	10.0	18	2	86	10.9	17	3
Second	249	7.5	17	1	189	8.5	16	1
Third	347	8.6	17	1	263	8.7	20	1
Fourth	343	10.9	20	1	353	10.4	19	1
Fifth	239	10.1	20	1	228	10.7	22	2
Sixth	94	11.0	22	1	92	11.5	20	2
Total or average	1,406	9.9	24	1	1,243	10.6	22	1

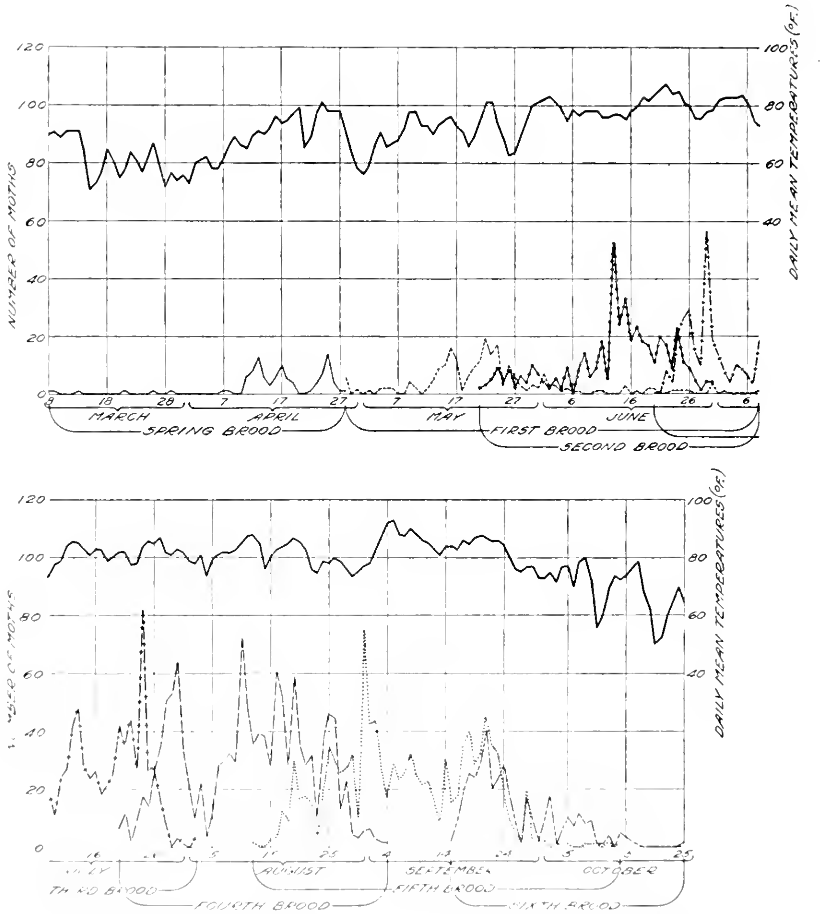

FIGURE 1.—Emergence of 3,751 oriental peach moths at Fort Valley, Ga., season of 1925

During 1926 records were kept on the length of life of 475 male and 508 female oriental peach moths. The males lived an average of 11.6 days and the females an average of 12.5 days. Table 15 gives the average, maximum, and minimum length of life of moths of each generation in 1926.

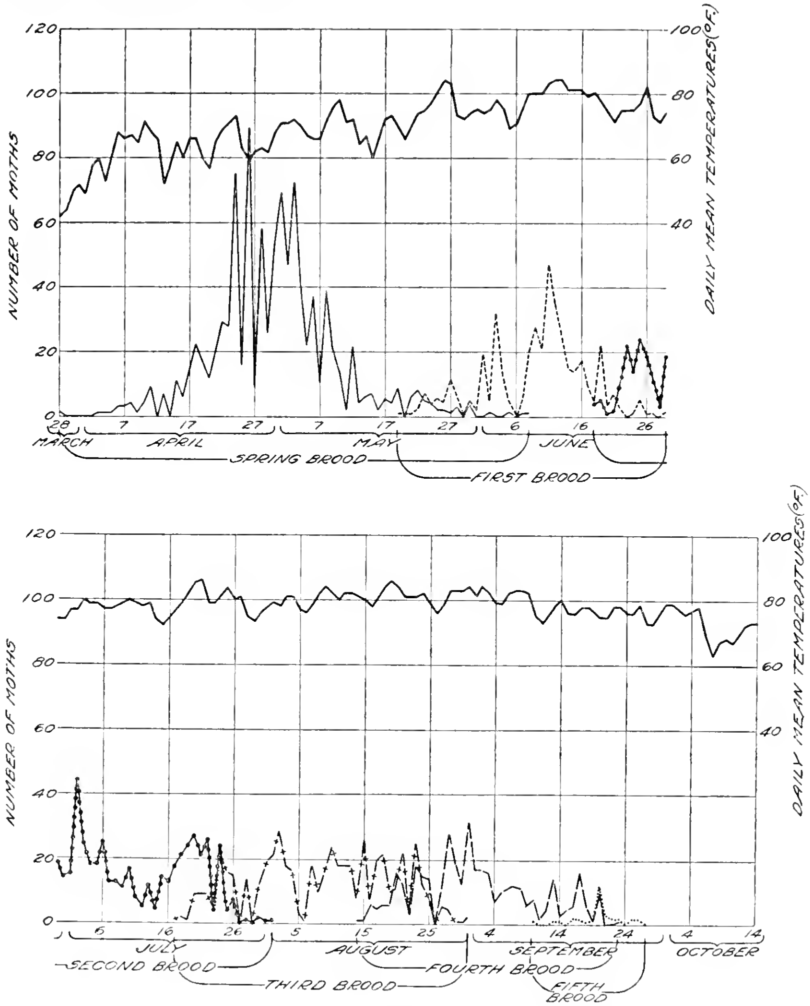

FIGURE 2.—Emergence of 2,960 oriental peach moths at Fort Valley, Ga., season of 1926

TABLE 15.—*Length of life of male and female oriental peach moths at Fort Valley, Ga., during the season of 1926*

Brood	Male moths				Female moths			
	Number	Length of life			Number	Length of life		
		Average	Maximum	Minimum		Average	Maximum	Minimum
		Days	*Days*	*Days*		*Days*	*Days*	*Days*
Spring	198	11.8	24	1	215	13.4	29	1
First	72	11.5	20	2	76	11.9	17	2
Second	65	11.5	20	2	68	11.8	22	2
Third	68	11.7	20	3	77	12.1	18	3
Fourth	65	10.9	16	2	65	11.2	19	3
Fifth	7	12.7	17	9	7	12.1	16	8
Total or average	475	11.6	24	1	508	12.5	29	1

SUMMARY OF THE LIFE HISTORY OF THE ORIENTAL PEACH MOTH IN GEORGIA

Table 16 gives a summary of the length of time required for each generation of the oriental peach moth to pass through the several stages in its life cycle. The average time required to complete the entire life cycle in 1925 ranged from 24.8 to 40.5 days, and in 1926 it ranged from 24.5 to 32.8 days. The first and last generations required more time to complete their life cycle than did those in midseason on account of the cooler weather in the spring and fall.

TABLE 16.—*Summary of the life history of the oriental peach moth in Georgia, 1925 and 1926*

Generation	Average length of incubation period of egg	Average length of larval feeding period in fruit	Average length of cocooning period	Average length of pupal period	Average length of life cycle	Average number eggs deposited per female
	Days	*Days*	*Days*	*Days*	*Days*	
1925:						
Spring	-------	-------	-------	13.3	-------	11.3
First	4.3	16.3	8.5	11.4	40.5	6.4
Second	4.3	11.3	3.1	8.8	27.5	16.9
Third	3.3	10.3	2.8	8.4	24.8	30.5
Fourth	3.2	12.0	2.9	8.4	26.5	62.9
Fifth	3.4	11.4	3.0	8.2	26.0	50.0
Sixth	3.5	14.7	2.6	8.3	29.1	66.4
Seventh	4.0	19.2	[1]	-------	-------	-------
1926:						
Spring	-------	-------	-------	18.7	-------	9.6
First	5.7	13.7	3.8	9.7	32.8	51.7
Second	3.7	11.1	2.9	9.3	27.1	44.6
Third	3.7	10.8	2.7	8.6	25.8	43.5
Fourth	3.4	10.6	2.5	8.1	24.5	56.9
Fifth	3.7	12.9	2.7	8.8	28.1	57.9
Sixth	4.2	16.5	[1]	-------	-------	-------

[1] None pupated.

PARASITES

Parasites of the oriental peach moth are apparently very scarce in the region around Fort Valley, Ga. A large quantity of oriental peach moth material was collected in the field during 1925 and 1926 in connection with the life-history studies, and from it only three parasites were taken. These were *Lixophaga variabilis* Coq. (Diptera) May 31, 1925; a species of Apanteles (Hymenoptera) June 16, 1925; and a new species of Eubadizon (Hymenoptera) June 14, 1926.

A considerable number of larvae collected in the field during 1925 and 1926 were found to be attacked by an undetermined wilt.

MISCELLANEOUS NOTES

TIME REQUIRED FOR LARVAE TO ENTER PEACH TWIGS

Two larvae in the third instar were removed from infested twigs of the new growth of a 2-year-old peach tree on April 16, 1925, and at 2 p. m. they were placed on fresh uninfested peach twigs. Larva No. 1 wandered about on the leaves for about five minutes and then started to rasp the tissue of the midrib of one of the unopened leaves at the tip of the twig. The leaf tissue was not eaten but was cast to one side as the larva worked, being held together by silk. By 3.30 p. m. the larva had bored in, and it disappeared into the stalk at 4.15 p. m. At 4.45 p. m. it had not bored farther than just to enter the stalk. Larva No. 2 had just molted when removed from an infested twig. At 3.30 p. m. it had spun a silken case around itself and had begun slowly to rasp the tissue. At 4.45 p. m. this larva ceased to work. In another observation a first-instar larva entered a peach twig one hour after it was placed on the plant.

WEEKLY COLLECTIONS OF INFESTED TWIGS TO DETERMINE ABUNDANCE OF LARVAE IN THE FIELD

In 1926 infested twigs were collected for one hour each week in two orchards in the center of the Georgia peach belt. The results of these collections, together with the average number of larvae which hatched daily each week in the insectary, are shown in graphic form in Figure 3. It is evident that the peaks in the insectary records correspond rather closely to those in field collections.

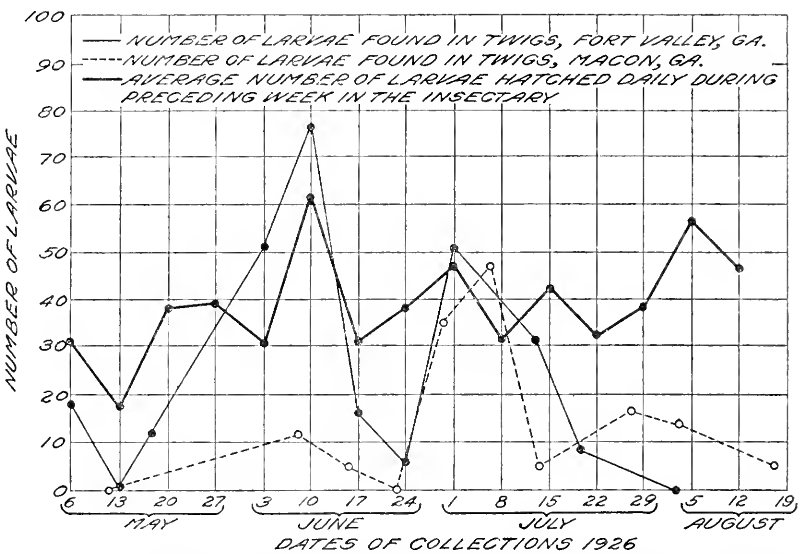

FIGURE 3.—Abundance of oriental peach moth larvae in the field, as determined from weekly collections of infested peach twigs, compared with the average number of larvae which hatched daily during the preceding week in the insectary at Fort Valley, Ga., 1926

The orchard at Fort Valley was an old bearing orchard, and the twigs had hardened by August 2. No further larval work was found in the twigs. The orchard at Macon was a well-fertilized 1-year-old orchard in which the twigs started hardening about August 3. Practically all the twigs had hardened by August 24, although a few larvae were found in twigs as late as October 15, these standing a much better chance of successfully hibernating.

FIRST APPEARANCE OF LARVAE IN THE FIELD

At Fort Valley, Ga., the first larvae found in the field in 1925 were seen April 10. They probably hatched April 6. In the insectary the first egg hatched April 19. In 1926, full-grown larvae were found in the field on May 5, and in the insectary on May 3. Second-brood larvae only a few days old were found in the field on May 26, 1926, while the first eggs of the second generation hatched in the insectary on

May 27. In 1927, the first larvae found feeding in the twigs in the field were seen April 2. In 1928, the first larvae (about two days old) were found in the field on April 25. The latest date on which a larva was found in the field was October 15, 1926, at Macon, Ga., when a nearly full grown individual, probably of the sixth generation, was observed feeding in a peach twig. According to the field notes the stages of each generation appeared in the field from two to four days earlier than they did in the insectary.

PLACE OF ENTRANCE OF LARVAE INTO HOST

Observations on 7 larvae on April 11, 1925, showed that 3 entered the shoots through the leaf petiole and 4 entered just below the base of the petiole through the stem. Of 2 others, 1 entered through the petiole, and 1 entered through the stem between nodes. One found in a commercial orchard on April 13, 1925, had entered through the stem. Five found in a home orchard on the same day had all entered through the stem. About 50 per cent of the larvae found in the field up to April 13, 1925, were working upward in the shoots from the place of entrance. Of 56 larvae entering peach fruits on May 14, 30 entered through the side and 26 through the stem end.

PLACE OF PUPATION

On June 17, 1925, two pupae were found in small hollow twigs on a tree at Fort Valley, Ga. Another was found pupating between peach and twig, and one old pupal case was found in the same position. On June 22, 1925, two pupae were found in a depression at the stem end of green peaches. On October 27, 1925, an examination was made of peach trees in a Macon, Ga., orchard, that contained varieties ripening from June to October, to determine the places of oriental peach moth pupation. Ten empty pupal cases were found above the crotches and 12 below. The adults had emerged from all cases. No cases were found on the trunks below the soil surface. Soil sifted from under three trees of a late variety contained no larvae, pupae, or empty cases of *L. molesta*. In November, 1926, 24 pupal cases were located in an orchard north of Fort Valley. All were on trees under bark, in split limbs, or at petioles of peach leaves. Two hibernating larvae were located in a hollowed-out twig from which the pith had been removed.

ABUNDANCE AND SPREAD

In the Fort Valley (Ga.) region the infestation in 1925 was confined to peach trees within the city limits of Fort Valley and Macon and to parts of seven commercial orchards. In 1926 there was a marked decrease in the infestation, and that year only a few trees within the city limits and parts of two commercial orchards were infested. There was an increase in 1927. An observation on April 4, 1927, in one of the commercial orchards infested in 1925 and 1926 revealed more larvae than ever before at that time of the year. There were about as many present as could be found at the height of infestation the summer before. The infestation within the city limits was heavy, and during the season the insect spread to orchards 12 miles north, 15 miles south, 6 miles east, and 6 miles west of the city of Fort Valley. However, the infestation was very light throughout the area. There was also an increased infestation in other sections of the Georgia peach belt in 1927. There was a marked decrease again in the infestation in the early part of 1928. The insect was late getting started in the spring. A commercial orchard north of Fort Valley that had always shown the heaviest infestation had less than one-tenth as many injured twigs in it on July 9, 1928, as it had had at the same time in 1927. During 1928 the insect spread 7 miles farther south, in the Fort Valley region, than the southern limit in 1927, and in one orchard near Marshallville the infestation was fairly heavy, but throughout the whole infested area in middle Georgia in 1928 the injury from the insect was of no economic importance.

STATUS OF THE ORIENTAL PEACH MOTH INFESTATION IN GEORGIA

The oriental peach moth has not been and is not now of any economic importance in the central Georgia peach belt. The chances are that it never will be a pest of major importance in that section unless fruit that matures late in the season is planted, because no host is afforded for the maturity of the last three broods of larvae. The harvest of the latest commercial variety of peaches is usually completed in central Georgia before the last three broods have been produced. By that time, on account of the hardened condition of the peach twigs, the larvae have ceased to work in them. Consequently, owing to the absence of a host after midsummer, there is an apparent heavy mortality of oriental peach moth larvae of broods that would otherwise hibernate.

Young growing peach twigs contain a considerable quantity of water-soluble sugars which the larva is able to utilize as food. During the hardening of the twig its growth is practically stopped, and the soluble carbohydrates are deposited in the pith and medullary rays in the form of starch, which is not available to the larva for food, as the necessary digestive enzymes are lacking in this insect. The decreased nutritive value of the twig and the increased difficulty of penetrating the hardened lignified tissues result in the starvation of a large number of larvae. In the latter part of the summer small larvae have very frequently been found dead within the tips of hardened twigs.

In 1925 fourth-brood larvae were making their appearance in the middle Georgia peach belt during the harvest of Elberta peaches, the last commercial variety to ripen in the State. No larvae of the fourth brood hibernated in 1925. The fifth, sixth, and seventh generations were reared in the insectary after the peach harvest that year, and 12 per cent of the fifth, 65 per cent of the sixth, and 100 per cent of the seventh brood larvae hibernated. In 1926, third-brood larvae were making their appearance in the middle Georgia peach belt during the harvest of the last commercial variety of peaches, but no larvae of that brood hibernated in 1926. The fourth, fifth, and sixth generations were reared in the insectary after the peach harvest that year, and 12 per cent of the fourth, 87 per cent of the fifth, and 100 per cent of the sixth brood larvae hibernated. Thus it appears that the broods of oriental peach moth larvae that hibernate in middle Georgia are not produced until after the fruit has been harvested and the twigs have hardened.

A few larvae yearly reach maturity late in the season in water sprouts or sucker growth of neglected orchards or in the twigs of late-growing trees. These are able to hibernate and start the infestation again the following spring. In an exceptional year, when late rains force vigorous twig growth late in the summer, a sufficient number of larvae may be able to reach maturity and hibernate to cause commercial damage the following season if conditions are then favorable for their increase.

In latitudes where the insect produces six or seven broods of larvae annually, its hosts would perhaps be subjected to severe attacks if field conditions were favorable for the rearing of the later generations. The heavy mortality of larvae of the broods that hibernate in middle Georgia has held this insect in check.

While the insect has been spreading in the Georgia peach belt since it became established, the infestations in the central part are light and are to date of no economic importance. In the northern part of the Georgia peach belt considerably heavier infestations have been reported by C. H. Alden of the Georgia State Board of Entomology, and the insect is likely to become of considerable economic importance there. In that section apples are raised, and the later broods of oriental peach moth larvae are able to mature in the fruit and hibernate in sufficient numbers to injure peaches seriously the following season.

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TECHNICAL BULLETIN NO. 151 — DECEMBER, 1929

VEGETATIVE PROPAGATION FROM THE STANDPOINT OF PLANT ANATOMY

BY

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AND
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UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D. C.

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By J. H. PRIESTLEY, *Professor of Botany, University of Leeds, England,* and CHARLES F. SWINGLE, *Assistant Pomologist, Office of Horticultural Crops and Diseases, Bureau of Plant Industry*[1]

CONTENTS

INTRODUCTION

The fundamental need for the standardization of horticultural products, which is largely attainable only through the greatly increased employment of vegetative propagation, has been repeatedly emphasized within the last few years (*112*, *162*).[2] The successful control of vegetative propagation involves a thorough understanding of the external factors, together with the internal conditions involved. Although the present study is chiefly a contribution to the knowledge of the internal factors, the importance of the interplay between the external environment and a complex organism is recognized, and where possible the influence of external factors upon the internal anatomical changes, as they proceed, will be discussed.

[1] So far as this bulletin represents the work of the junior writer, it was chiefly done while he was a collaborator of the U. S. Department of Agriculture, under a National Research Council fellowship in botany. To the National Research Council and to the International Education Board he gratefully acknowledges the receipt of this grant. Many of the anatomical details here presented were obtained by Miss Lettice M. Woffenden and Miss Ursula Tetley, partly at Leeds and partly at Merton, while working under grants from the John Innes Horticultural Institution. The writers are also indebted for many other details to Miss R. M. Tupper-Carey, to various other members and students of the botany department, and to Mr. J. Manby, photographer, of the University of Leeds. Much of the matter contained in this bulletin was presented at the conference on vegetative propagation held at Washington, D. C., April 5, 1927.

[2] Reference is made by italic numbers in parentheses to "Literature cited," p. 89.

No attempt has been made to restate the problems of vegetative propagation in directly practical terms. A number of standard works on horticulture deal with the art of plant propagation, and the reader desirous of specific instruction as to how to propagate a given plant is referred to them (*6*, *189*, *26*, *62*, *72*, *100*, *101*, *8*, *38*). This bulletin is concerned rather with a critical anatomical examination of the internal factors involved in vegetative propagation, though primarily, it is true, for such light as can be thrown upon those forms which now offer more or less difficulty in propagation.

It is certain that the behavior of the plant is closely correlated with its structure and mode of growth. Thus the possibilities of vegetative propagation among monocotyledons, where growth activities are confined to the apical meristem and certain intercalary nodal regions, are more limited in scope and are different from the regenerative possibilities possessed by the dicotyledons and gymnosperms, in which cambial tissues are usually present. This is a clear indication that structural features of the plant are of primary importance in connection with its propagation by vegetative means, and it is from the point of view of plant structure that the problem is considered in the following pages.

THE PROBLEM IN TERMS OF PLANT ANATOMY

By vegetative propagation is meant the process of obtaining asexually an entire plant from a portion. This commonly, but not always, means cutting the plant into pieces and growing complete plants from the bits. With the more simply organized plants the process occurs on a wholesale scale, but in the following pages the writers are concerned with this phenomenon only as it occurs in the flowering plants and, unless otherwise indicated, only in the dicotyledons. These plants consist in the main of shoot and root, the shoot developing from the usually upward-growing shoot apex and the root from the downward-growing root apex. In the seedling plant all this complex organization has emerged from the seed, and ultimately from one single cell in the seed, the fertilized egg cell. The complex organization thus developed is still built up of cells. Though they remain minute they may be exceedingly numerous, and no limit seems to be set to their continued multiplication so long as conditions remain favorable for growth. Hence, if the proper conditions are present, cell multiplication in the fashion characteristic of the individual plant will provide indefinitely a means for plant growth and under certain circumstances therefore for vegetative propagation.

As long as a single cell of the plant remains alive there are reasons for considering that potentially, if it is capable of growth, it is able to give rise to a whole new plant. But in practical experience it has been found that, although individual cells isolated from vegetative parts of the flowering plant may live for months, no one has thus far succeeded in obtaining new plants from them. If, however, instead of single cells, sufficiently large groups of cells are isolated, they may be able to reproduce the whole plant and thus achieve vegetative propagation. The problem of cell multiplication in the higher plant can not, then, be separated from the problem of the organization of cells into the structures characteristic of the higher plant, primarily the shoot and the root. Thus the problem of vegetative propagation becomes that of the development of new shoots and new roots upon isolated pieces of shoots or roots.

Both shoot and root are very complex organizations of living cells, which themselves are but little understood entities, and it is in terms of this organization that the problem must first be visualized. In the higher animals growth occurs as a widely distributed process and takes place simultaneously throughout the greater part of the organism. In the higher plants, on the other hand, the growing regions are largely localized at certain apical growing points. It is here that the characteristic features of the shoot and the root are laid down and that the leaves and reproductive organs are first formed. Ultimately, the differences between shoot and root are to be looked for in the differences in organization between the two types of apical growing points.

In these apical regions the unit of construction is singularly uniform throughout all the flowering plants. It is a relatively small cell compared with the size of cells in other regions of the plant. This "meristematic" cell consists mainly of cytoplasm and nucleus, is of a semifluid consistency, and contains no aqueous drops of sap in any recognizable vacuoles. The nucleus, which is usually central in the protoplast, usually appears rounded like a spherical liquid drop in a liquid medium. There is no doubt that this living cell is a very plastic mass of protoplasm. Behind these meristematic cells other cells are expanding with the intake of water and are vacuolating so that in many cases, as a result, the plastic meristematic cells are stretched over the growing point. The walls of the cells making up the growing point are thin envelopes of cellulose cemented together by a plastic matrix, pectic in nature. The internal hydrostatic pressure does not distend the cells sufficiently to cause them to round off from one another; hence their walls remain in continuous contact and no intercellular spaces appear. Each cell is primarily engaged in the same activity, the construction of living protoplasm out of the simple nutrient materials supplied to it. As a result of such activity the protoplasmic mass increases in both nucleus and cytoplasm until a certain definite limit of size is reached, when cell division occurs and two daughter cells of about the size of the original cell are formed. Through the continuous repetition of this process of growth and division the size of the meristematic protoplasts is maintained within narrow limits. This is a description of the fundamental process of growth as it takes place at the growing point, expressed in terms of the cell units.

Such a continuous construction of new protoplasm requires a continuous supply of nutrient materials. Presumably, this is taken in by the individual protoplast over all its surface, which is in contact with its cellulose envelope. If the whole mass of the protoplast is engaged in the process of protoplasmic synthesis, then with increase in size the mass of protoplasm will increase out of proportion to the surface through which it is nourished; hence, these repeated cell divisions serve to maintain the balance between surface and mass.

The process so far described is characteristic of any meristem at a growing apex, whether of shoot or of root. The differences between individual plants, and still more those between shoot and root of the same plant, in the main must be attributed to differences in the organization of the aggregate of these cells at the growing apices. Certain differences between the arrangement of the cells at the shoot apex and at the root apex are immediately discernible. At the shoot apex these meristematic cells are found at the surface of the growing point, whereas those at the root apex are found beneath certain vacuolated, differentiated cells making up the rootcap. Recently this difference in organization has been correlated with differences in the chemical nature of the walls intervening between the living protoplasts (*113*, *121*) and thus with the nutrition of the protoplasts, because, as already pointed out, the nutrient materials required in the process of protoplasmic synthesis must ultimately reach the individual protoplast through the intervening walls.

Fortunately, the cell walls in these two apical regions show definite differences in microchemical reaction to the iodine cellulose reagents. Although the meristem walls in the region of the shoot apex give the normal blue reaction with iodine in potassium iodide immediately after treatment with 70 per cent sulphuric acid, and with chloriodide of zinc after brief previous treatment with cold aqueous or alcoholic potash, sections of the root apex show neither of these reactions unless they have previously been vigorously boiled in strong alkali. This difference in microchemical reaction has tentatively been correlated with the presence in the root apex of substances, both protein and fatty in nature, which are intimately associated with the cellulose and pectin of the walls in such a way as to mask the characteristic cellulose reactions (*168*). In the shoot apex the only masking substances present in the walls seem to be fatty in nature, and these are much less firmly held by cellulose, so that they are removed by brief treatment with cold alkali. In the case of the shoot apex, most of the fatty substances originally present in the walls when they were first deposited between the dividing protoplasts seem to have "creamed" to the external surface of the shoot. Here they have linked up into a continuous thin fatty layer containing a certain amount of unsaturated chemical compounds such as are always present in vegetable oils. These begin to oxidize and dry and thus form the thin cuticle (*84*, *85*, *110*) which has many of the properties of varnish.

Saying that the carbohydrate mixture of the walls which intervene between the protoplasts of the root apex is impregnated with protein and fat is probably only another way of stating that when the carbohydrates were deposited at the interface between two dividing protoplasts the living protoplasm was incompletely withdrawn from the intervening region, so that the fats and proteins characteristic of the protoplasm are still found in the wall (*115*). These walls separating the meristematic masses are probably of great importance as channels of nutrition for the actively growing protoplasts, and their behavior in this respect is likely to be materially affected by the retention of considerable quantities of the main protoplasmic constituents. If it is assumed that the cellulose wall of the normal plant cell is completely permeable to both water and the solutes contained in it, then the characteristic semipermeability of the living cell is to be ascribed to the protoplasmic envelope within. If, however, sufficient protoplasm is retained within the cellulose wall, this will become much less permeable; when this occurs the behavior of the wall may be expected to be more like that of gelatin than that of filter paper. In aqueous solutions this may well mean that while still permitting diffusion or molecular movement of solutes through the wall, it resists flow or movement of liquid en masse through the wall. At this point the differences between the meristem walls of the shoot and root apices must be left, until with a wider knowledge of the structure of the shoot and of the root the problem of the nutrition of these special meristems can be more fully visualized.

It is difficult to form a comparative estimate of the rate of growth of meristematic cells; but as the processes of growth always involve an increase in size between certain narrow limits, following which cell division occurs, and as the process of division itself requires approximately the same time to take place in each case at a given temperature, in comparing one layer of cells with another a rough estimate of their comparative rates of growth can be made by determining the percentage of cells in similar sections of each layer which are found to be in certain stages of cell division. Comparisons by this method have been made by Schüepp (*139*, *140*) for the shoot and by Lundegårdh (*92*) for the root, with results that will now be considered in some detail.

THE SHOOT APEX

Typical meristematic cells are found at the surface of the shoot apex and for a certain number of layers within. (Pl. 1, A.) Schüepp found that throughout all these layers the proportion of cells in division stages was about the same and that the rate of growth of these cells thus does not appear to be affected by their positions (*139*, *140*). On the other hand, the arrangement of these cells shows that the direction of cell division is not the same throughout all layers. The surface layer, or dermatogen, and the next layer or two, Hanstein's periblem (*53*), invariably divide by the formation of new cross walls at right angles to the surface of the plant. The result is that all new cells thus formed are added to the layer in which they arise and do not contribute to the core of the shoot, over which these surface layers may be regarded as stretched.

In the case of the inner meristematic cells, which divide at the same rate as the outer ones, the divisions are not always in the same plane, so that in this plerome region new cells are being added to the meristematic layer and to the core within. But if new cells are thus being added at the same rate in both regions, in the outer layers only in the superficial plane and in the inner layers in depth as well as in surface, then the only possible result will be a more rapid increase of the surface than of the mass within. Such an increase, in terms of cell division, is represented by the appearance, in the layer beneath the dermatogen, of walls that are no longer at right angles to the surfaces, cells thus being thrust outward from the surface; hence, quite close to the apex are formed folds, the new leaf initials (*140*). Thus it is seen that the superficial leaf initials are the natural result of the method of organization of the meristematic tissue at the shoot apex.

Beneath these characteristic meristematic cells clothing the surface of the shoot apex and continually throwing up folds upon it as it grows are found cells that are changing in various ways. They are vacuolating and thus are growing larger as they become distended with sap. They are forming relatively less protoplasm but more carbohydrate; thus more cellulose is being deposited upon the walls, although at first the rapid extension of the wall prevents any very noticeable increase in thickening. For a time these cells are also forming starch, but this is so rapidly hydrolyzed by the water entering the cells during vacuolation that except when the shoot is grown in the dark (in which case vacuolation is a slower process) this temporary appearance of starch in the meristematic tissue is often missed (*115*).

As the elastic walls of the cells extend under the hydrostatic pressure exerted by the accumulating sap within, they tend to assume a spherical form. The resultant strain upon the amorphous pectin deposit which cements the cells together is too great and intercellular spaces arise. In the early stages at the growing apices these interstices are filled with sap, which only later is displaced by air (*117*). These cells still, although more slowly, continue to divide, and the rate of protoplasmic synthesis likewise slows down; the cells enlarge, but a great part of each cell is now filled with dilute sap, and the protoplasm, which is now also less dense and more watery in nature than previously, is restricted to a narrow envelope between the vacuole and the wall. The nucleus is still dense, and probably in this type of cell, as Gerassimow's experiments have indicated is the case in similar vacuolated Spirogyra cells, growth, so far as it involves the formation of new protoplasm, is now restricted to the nucleus (*39*, *40*).

In the shoot apex, vacuolation first appears behind the dome of meristematic cells in the center, which is the region of the future pith. It next appears in the cortical region. Between these two regions of vacuolating cells lies a cylinder of cells which are still meristematic and which, therefore, are compressed between their expanding neighbors on either side. This region is the procambial ring. As the cells are squeezed between the cells within and without, being plastic they extend vertically or longitudinally. Such extension converts them into lathlike cells in which increase in mass is not accompanied by a relative decrease in surface, so that as long as they remain meristematic they can continue to synthesize protoplasm. Thus arise the elongated cells of the procambial strand, from which later the vascular elements differentiate. The protoxylem elements differentiate on the inner side of this ring and the protophloem elements on the outside. In the shoot the new vascular elements thus formed are always isolated from the main vascular strand beneath. They seem rather to be associated with the new leaf initials, appearing first in the procambial ring just where a strand diverges from it and enters a leaf initial. As the isolated xylem elements differentiate, their protoplasts become more permeable, and all cell contents ultimately are lost. Previously, however, owing to the osmotic pressure of the relatively concentrated sap within, such a cell may expand, because it constitutes a system which withdraws water by osmosis from the less concentrated sap in the general vascular system below it in the shoot.

This process of differentiation in the procambial strands appears to be of great importance in the nutrition of the superficial meristem of the shoot. It seems quite probable that water is thus being continually withdrawn from the main supply below and then driven forward into the tissues surrounding the differentiating vascular elements, and with the water would go solutes from these differentiating vascular elements. Thus the protophloem differentiation, of which but few details are yet known, involves a sudden swelling of the developing element, a disappearance of the dense, protoplasmic contents, and a thickening of the wall, along with the assumption of a striking, pearly, highly refractive appearance. These phenomena are followed by the total collapse of the element. The solutes which were thus in evidence must have gone somewhere when they disappeared as the element collapsed; perhaps they added to the solutes present in the sap released by the differentiating xylem, all being then pushed forward into the superficial meristem by the rising tide of sap. And apparently only such a flow of liquid could account for the adequate maintenance of nutrient supplies to the superficial layer of the meristem, so that this layer is able to grow as fast as any layer within. Diffusion does not seem to account for the continuous delivery of solutes to these cells, which are usually more than 10 cell layers, and sometimes 100 or more cell layers, from the end of the nearest differentiating xylem element.

THE ROOT APEX

An attempt by Lundegårdh to determine the proportion of cells in certain division stages in different layers of the root apex (*92*) led to results very different from those obtained by Schüepp for the shoot (*139*, *140*). In the root, the cells to the inside of the meristem, those in the plerome region, were found to be growing by far the most rapidly; the cells farther out showed a rapid falling off in the rate of growth, and the differentiated cells at the outside of the root apex showed no growth at all. (Pl. 1, B.) Other differences in organization are known to be associated with this; the inner cells grow the most rapidly and divide principally by walls laid down at right angles to the main axis of the root, so that most of the new cells contribute to the growth in length of the root. Therefore, there is no tendency for the formation of superficial folds at the root apex, and no exogenous lateral members are formed. Thus it is clear that the main characteristics of root growth are also directly due to the general organization of the meristematic tissues at the apex.

Here, again, vacuolation occurs in the cells behind the meristematic apex, usually first in the cortical cells, in which region also intercellular spaces form first. As in the shoot, these spaces are at first filled with sap, but farther behind the root apex they become displaced with air. The cells within are still meristematic and are compressed by the expanding cortex. They form the stele and are bounded on the outside by the cells which later form the pericycle and the endodermis. As already pointed out, the walls of these cells, unlike those of the corresponding cells in the shoot apex, are as yet heavily impregnated with fatty substances and proteins. Though these substances leave the walls more slowly in the root than in the shoot, they do gradually migrate, and because of their effect on surface tension they tend to accumulate at any surface where the liquid matrix is in contact with air. But as they thus move outward, air is diffusing inward from the intercellular spaces in the cortex, and thus the fatty substances tend to oxidize and condense in a varnishlike strip on the radial and transverse walls of the endodermis (the outermost envelope of cells clothing the stele) inside which air spaces have not yet appeared. Thus the characteristic Casparian strip, an invariable constituent of the endodermal walls in roots of all the flowering plants, is formed.

This Casparian strip appears to be of fundamental importance in the further development of the root. All the vascular differentiation in the root takes place within the endodermis, and the solutes which are released by the differentiating vascular elements are retained within the stele, because outward movement along the walls is precluded by the continuous fatty deposit in the Casparian strip on the radial and transverse walls of every cell of the endodermal cylinder (*119*). Water and solutes may pass outward or inward, moving from cortex to stele and vice versa; but such movement must take place across the protoplasts of the endodermis and is, therefore, under protoplasmic control. Furthermore, this varnishlike layer of the Casparian strip rapidly sets, forming a relatively rigid structure; thus as the cells of the stele within vacuolate, their tendency to expand and round off against one another is materially restricted by the resistance offered by this fine network. As Schwendener (*141*) long ago pointed out, the expansion of the tissues within against this network produces a relatively rigid structure, much as the gas envelope of the balloon may swell against its limiting cord network until it forms a relatively rigid entity. One result is that intercellular spaces are but little developed within the root stele; but still more important, even when formed, in the young developing root they have never been found to contain air, because there are no air spaces in the endodermal cylinder and no air bubble can work past the Casparian strip which firmly cements the cells of the endodermal cylinder together. Within this root stele, vascular differentiation proceeds, but in a very different manner from that taking place behind the shoot apex. Here, in the root, such differentiation takes place much nearer to the deeply sunken meristematic tissue, the differentiating elements being in continuity with the vascular elements already formed. This means that there is little tendency toward the fluctuation of sap pressure such as would be brought about by the appearance and disappearance of new isolated osmotic systems. But the walls intervening between vascular elements and meristem cells are different in nature from the corresponding cells in the shoot. In the root such walls are impregnated with protein and fat which probably offer considerable resistance to flow but not to diffusion. Since there are no fluctuating sap pressures in the root, it must be assumed that the solutes are supplied to the layers beyond the vascular elements largely, if not entirely, by diffusion. Such solutes certainly become available when the protophloem elements swell up and collapse, and the protoxylem elements lose all their organic contents, only a part of which can be retained upon their walls.

But can diffusion supply the necessary solutes with sufficient rapidity to the meristem cells? There can be no doubt of this, provided the distances are sufficiently short. Hill has recently pointed out (*59*) that while the chemist regards diffusion in liquids as a comparatively slow affair, this is because he is dealing with comparatively large space units. Before a steady state is reached, substances are transmitted by diffusion with a speed inversely proportional to the square of the distance, and though this may appear to be a slow method of transmitting substances across a distance measured in centimeters, when the distance is of the order of thousandths of a centimeter, the process will proceed one million times as fast. Between the ends of the differentiating vascular system in the root and the innermost layer of meristem of the root apex, the distances are always measured in microns, as never more than a few small cells intervene. The total distance rarely exceeds a few hundred microns, and for such distances diffusion constitutes an extremely efficient agency for the delivery of nutrient solutes. Moreover, this furnishes a good explanation of why the rate of delivery of the solutes in the root, and with it the rate of growth, falls off with great rapidity in the outer layers of the meristem. Hence it is seen that the difference between the method of nutrition of the shoot meristem and that of the root, determined by differences in the microchemical nature of the walls separating the protoplasmic masses, seems to play the predominant rôle in determining the distribution of growth activity in these two meristems, and thus to determine the general organization of the shoot and the root, new exogenous lateral members appearing only at the shoot apex. If the nutrient supplies reaching the root are adequate, meristematic growth may continue indefinitely, but the new meristem cells must always be found near the vascular supply. New groups of meristem cells do arise in the flanks of the vascular elements within the endodermis, the walls of the protoplasts outside the endodermis being cut off from such supplies (*120*). These new meristems, which give rise to new branch-root apices, form just within the endodermis, in the pericycle, which is a layer made up of living cells relatively slow to vacuolate.

In the light of the foregoing brief analysis of the general structural organization of shoot and root apices, it is possible to take up the consideration of the problems involved in vegetative propagation, which include the formation, in isolated portions of plant tissue, of new shoot apices, new root apices, or both.

Such new shoots and roots, formed as a result of artificial conditions involved in propagation, usually may be regarded as examples of adventive structures. The origin of shoot apices obviously presents different anatomical problems from the origin of root growing points. The origin of adventive shoot and root apices will first be examined in the light of some detailed studies of their formation in isolated pieces of the root of seakale (*Crambe maritima*).[3]

VEGETATIVE PROPAGATION OF CRAMBE MARITIMA

FORMATION OF ADVENTIVE SHOOTS

The organization of the shoot apex and that of the root apex have now been considered. Both types of apices consist in the main of

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[3] The authority for the species is given in this bulletin only for forms not listed in Standardized Plant Names (*3*).

meristematic tissues, apparently similar as regards the structure of the individual cells of which they are composed, but differing between root and shoot in arrangement and organization, both in the meristematic tissues themselves and in the differentiating tissues which arise from the meristems and which probably are very important in their nutrition. The problem of vegetative propagation as generally considered involves the production of such an organized meristematic tissue in some region where normally it does not occur or where if present at all it is dormant at the time a portion of the original plant is isolated.

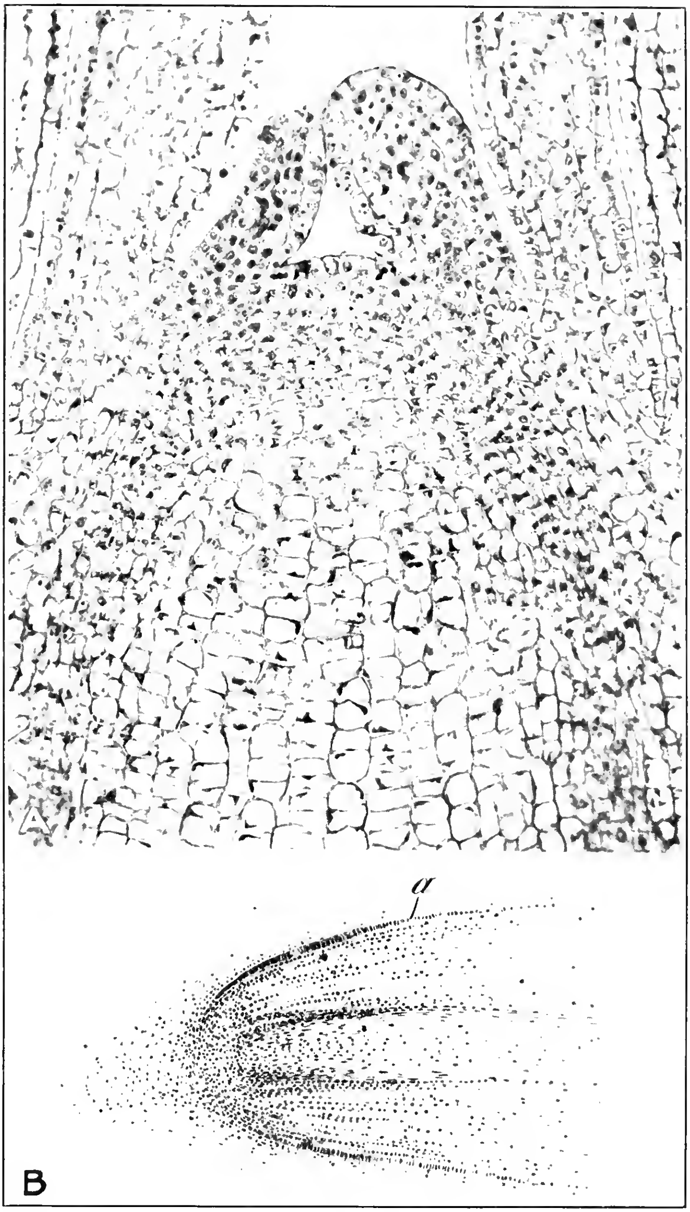
The place of origin of such an adventive growing point differs in different cases of vegetative propagation, but the fundamental problem is always the emergence of an organized meristematic apex from tissues of a different character. Therefore, before attempting a generalized statement of the various ways in which such apical organizations may be induced to appear, it will be well to consider one case in detail and to discuss in turn the problems presented in the different stages of development in such a complex process. Both the processes of shoot and root organization can very well be studied in the regeneration seen at the cut surfaces of pieces of the fleshy root of *Crambe maritima* (Cruciferae).

BUD PRODUCTION

Root cuttings are commonly used in propagating seakale, although it may easily be grown from seed. The root cuttings are sown in the field in the spring, and the roots of the resulting plants are dug in the fall; the lateral roots are trimmed off and stored for sowing the following spring, and the large main roots, which are 2 to 5 centimeters in diameter and about 10 to 20 centimeters in length, are planted in a darkened forcing bed in the greenhouse. Within a few weeks these roots will have expended themselves in throwing up etiolated shoots, each perhaps a meter high and as thick as the root itself. Neither these shoots, which constitute the commercial crop, nor the old roots are commonly used for propagation.

NORMAL ANATOMY OF ROOT

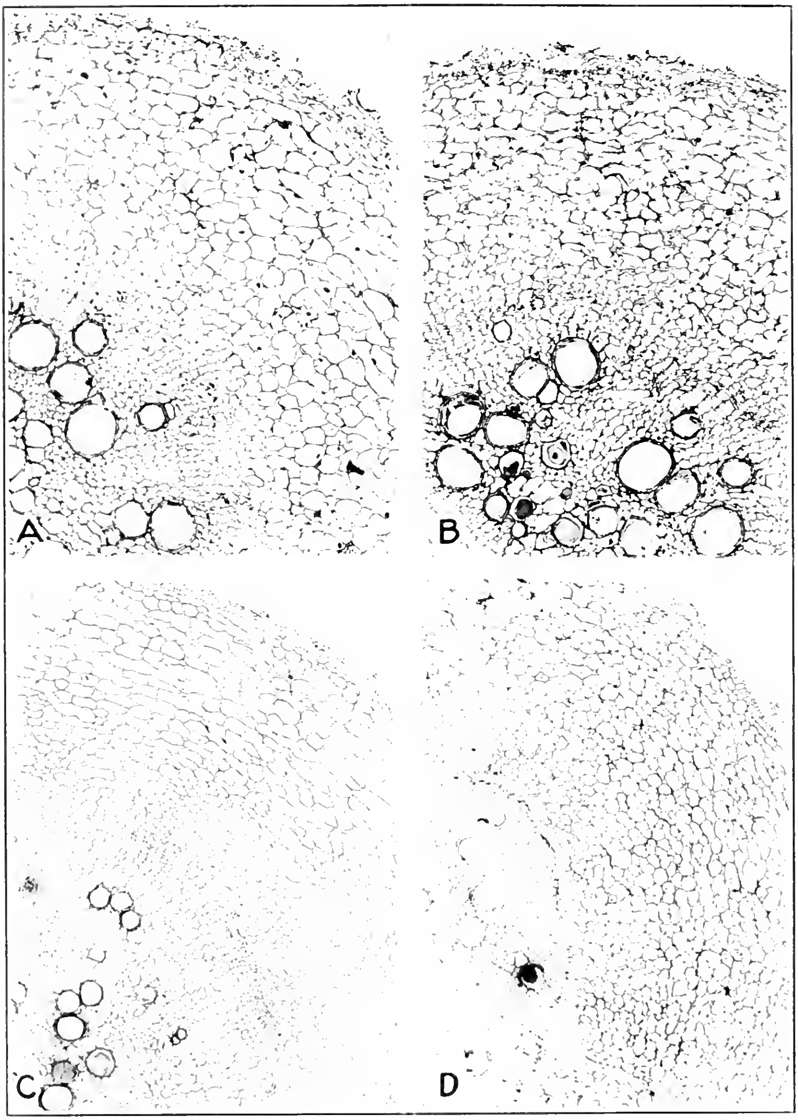
A cross section through a seakale root of the size used for root cuttings (pl. 2, A–D) shows a small core of primary wood, surrounded by a wide ring of very parenchymatous secondary tissue. In the xylem a few vertically extended lignified elements are scattered in radially arranged groups; but in the sectors opposite the protoxylem groups most of the tissue consists of somewhat prosenchymatous parenchyma, for the most part with the long axis of the cells parallel to the axis of the root. Under these circumstances the bulk of this tissue, although filled with starch, seems better described as xylem parenchyma than as ray parenchyma; it is regularly arranged in radial serial order (pl. 3, C), the small amount of expansion of the occasional lignified vessels not leading to any serious distortion, though the parenchyma cells in the immediate neighborhood of these vessels remain small, apparently compressed by their lignified neighbors, and free from starch. These cells, judging from their subsequent behavior in isolated root pieces, seem to retain many meristematic qualities.



THE APICAL REGIONS OF THE PLANT (LONGITUDINAL SECTIONS)

A.—Shoot apex of *Syringa vulgaris*. The youngest pair of leaf initials and the cells crowning the apex of the shoot are still completely meristematic. Beneath the apex the vacuolating but still dividing cells of the pith are visible, where longitudinal extension is associated with a series of transverse divisions. To either side the longitudinally extended, still meristematic cells of the procambial strands are evident. × 250.

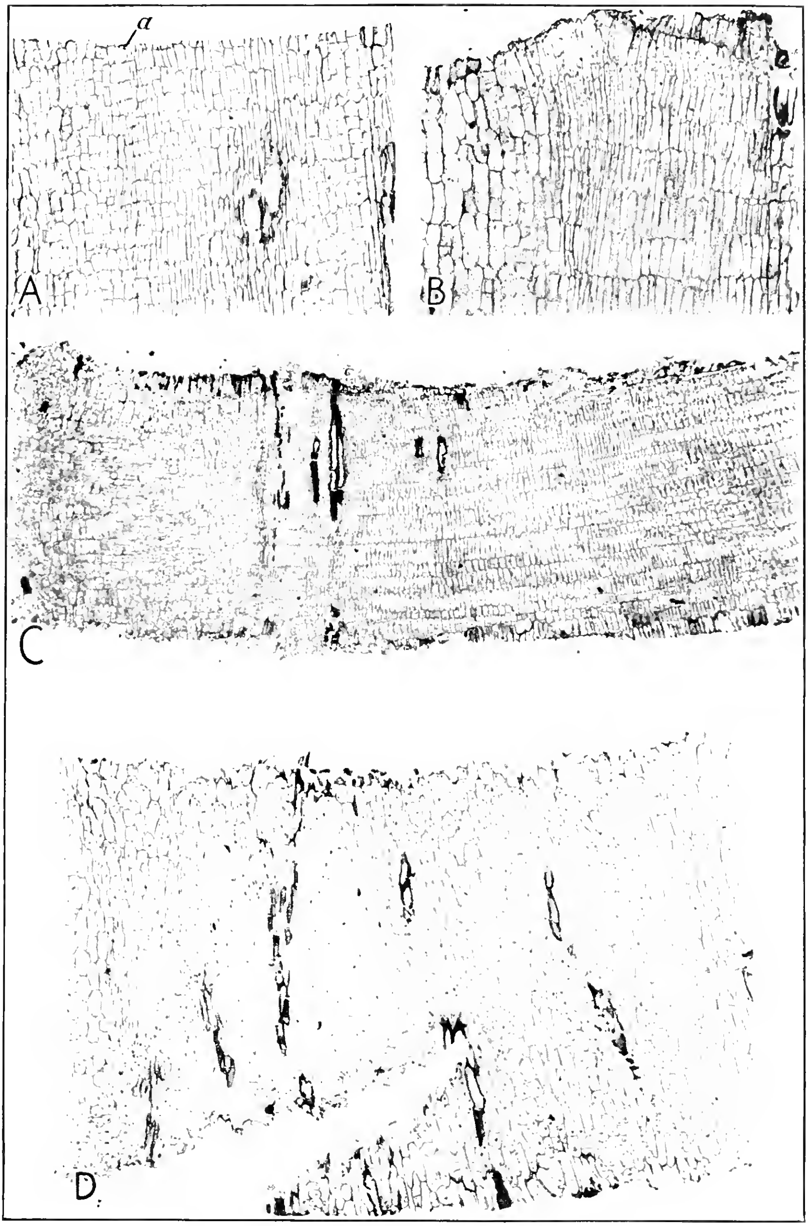
B.—Root apex of Chlorophytum. The outer cells of the rootcap are vacuolated and have ceased to divide. Behind the dense meristematic apical region vacuolation is visible in the central and the cortical regions; between these two regions lie the meristematic cells of the pericycle and the endodermis. The protoderm (*a*) can be traced well into the apical region. × 40.



DIFFERENCES IN CAMBIAL ACTIVITY AT OPPOSITE ENDS OF CRAMBE ROOT CUTTINGS (TRANSVERSE SECTIONS)

A and B. From 4-day material. × 65. A, Proximal end. Cambium activity is very slight and is restricted to the fascicular cambium. B, Distal end. Meristematic activity is indicated across the rays and around some of the xylem vessels.

C and D. From 7-day material. C, Proximal end. Meristematic activity is more extensive than in A, but is still chiefly restricted to crescent-shaped regions just within the youngest phloem. Some activity is also indicated around the xylem vessels. × 40. D, Distal end. The activity of the vascular cambium, which has increased in intensity and extent over that shown in C, extends right across the rays. × 45.



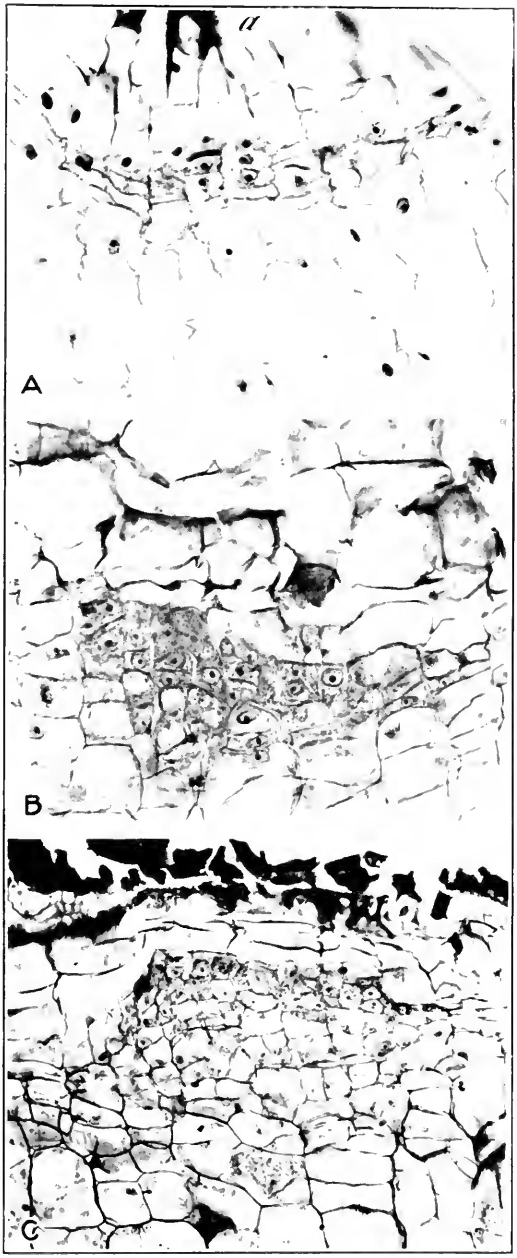
MERSITEMATIC ACTIVITY IN ISOLATED ROOT PIECES OF CRAMBE (LONGITUDINAL SECTIONS)

A.—Appearance of tissues beneath freshly cut surface. The phloem lies to the left of the cambium (*a*). × 35.

B.—A similar region three days after cutting. Cells cut through are collapsed and dying, and the walls of those immediately beneath show suberin deposits; starch has disappeared from the living cells below these, but not from the rest of the tissue. This disappearance has proceeded most actively in the neighborhood of the cambium. × 40.

C.—A very thin root slice after three days, showing suberin deposit and beginning of phellogen activity on both surfaces. The section is almost exactly radial and shows the very regular arrangement of the secondary tissues. As in all such short root pieces, there is very little difference in the degree of suberization and extent of phellogen activity between the upper (proximal) and the lower (distal) surfaces. × 20.

D.—After 14 days, suberization and phellogen activity are more marked at the distal surface. Compare extent of suberization and phellogen activity at the two sides of the tear accidentally left on the distal surface when the slice was cut. × 35.



FIRST STAGES IN ADVENTIVE-SHOOT DEVELOPMENT ON CRAMBE ROOTS

A.—Indications of the suberized layers (very heavily stained) at *a*; beneath this are a few wide periderm cells, with typical phellogen showing beneath them on the left. In the center the meristem cells are becoming more nearly isodiametric. × 210.
B. A slightly later stage. It is now clear that cells beneath the isodiametric cells in the bud initial are themselves becoming meristematic. Typical flattened phellogen cells, with compressed nuclei, are plainly visible on the right. × 235.
C. A young bud initial appearing in the wound phellogen formed on the side of a piece of xylem cut out from the root with a cork borer. × 210.

On the phloem side of the cambium a similar type of prosenchymatous cell, also arranged in regular serial order near the cambium, is recognizable. As these cells are pressed farther to the outside they become more rounded off from one another and the intervening spaces become very marked and apparently filled with air. At this stage the cells tend to become more nearly isodiametric, because, thus forced to the outside, they have plenty of room to expand, and the regular serial arrangement of the tissues is lost. While the phloem elements near the cambium show sieve plates with callose deposited in the transverse walls, along with lattices on the radial walls, and some evidence of contents characteristic of sieve tubes, much of the secondary phloem is simply storage tissue, most of the cells being filled with starch. Occasional myrosin storage cells are present here as well as in the xylem parenchyma; occasional lignified fibers, either in groups or scattered singly, are also found in the phloem parenchyma. The original elements of the primary phloem are not visible in the periphery. Usually the bounding layer of periderm is somewhat irregular in outline, as ruptures occurring during expansion have been followed by reformation of periderm at deeper levels. The periderm originally arose in the pericycle of the root just within the endodermis.

The young root shows a well-marked endodermis, immediately outside of which are found the curious thickenings of the radial walls of the inner cortical cells. These radial markings which are characteristic of the Cruciferae have been fully described by Van Tieghem (*170*).

Seakale does not seem to offer any exception to the general rule stated by Solereder (*149*), namely, that intraxylary phloem does not occur among any of the Cruciferae.

Active regeneration of both shoots and roots can be seen in pieces of these fleshy roots 2 to 3 centimeters long if they are simply laid horizontally on filter paper in a Petri dish and kept under warm, moist conditions. The observations reported in the following paragraphs are based on such pieces of roots which had been in a germinator at 23° C. for periods of three days and longer.

HEALING OF THE CUT SURFACE

Suberization

A necessary preliminary to all successful vegetative propagation is that the isolated piece of tissue should remain healthy. Necessarily, isolation has involved the exposure of the cut surface, and the first thing that must be considered is the conditions under which the wound surface remains free from serious invasion by the microorganisms which have been offered an ideal medium for growth. Frequently rapid decay does take place at the cut surface, and the cutting disintegrates before the new growing points can be regenerated.

The cut surface in a parenchymatous tissue—other considerations enter when the cut is made across a woody tissue as in the case of hardwood cuttings (*155*)—is always covered immediately by sap and débris from the crushed and broken cells that lay in the path of the knife. This gradually dries, forming a somewhat sticky film, but during the process it constitutes an ideal medium for many microorganisms, and it may be taken for granted that colonies of such organisms are always to be found here. Even the saprophytic organisms, though they may be unable to penetrate the living protoplasts themselves, will be able to spread along the cellulose walls between, in many cases digesting the pectic or cellulose constituents of these walls and disorganizing the tissues generally.

Such disorganization will be followed by death and decay; hence, unless changes in the walls beneath the cut surface, such as prevent the inward migration of microorganisms, take place more quickly than the latter grow and multiply, decay is bound to follow. Such changes in parenchymatous tissues seem usually to be brought about by the deposition, upon the carbohydrates in the wall, of a film made up of fatty substances which rapidly oxidize and dry, in the same way that similar films of unsaturated vegetable fatty substances, when exposed to the air, set to form compounds of a varnishlike consistency. (Pl. 3, A and B.) Such films resist digestion and direct physical penetration by all microorganisms if formed in time.

These deposits, which are obviously of great practical importance, are usually recognized by their reaction to fat stains such as Sudan III. It is necessary in considering the conditions of their formation to examine both the sources of the fatty substances from which they are formed and the conditions under which they set to a suberin deposit. Since the writers' observations upon seakale, so far as suberization is concerned, were by no means so extensive as the investigations that have been carried out with other plants, especially potato tubers, these remarks about suberization are somewhat general and not primarily concerned with seakale. However, so far as experimentation with seakale has been made, all that is said applies equally to it.

The fatty substances themselves undoubtedly arise from the sap which injects the intercellular spaces and the cell walls in the region of the cut. Such a cut can not be made without the cells near the wound (although not actually in the path of the knife) being so strained that an increase of permeability, usually temporary in nature, is brought about in the still-living protoplasts. If this strain is too severe, the increase in permeability is irreversible, and the cell dies. Janse (*67*, *68*) has shown how widespread is this increase in permeability of the living cells as the result of shock. The intercellular spaces in the neighborhood of the cut gradually fill with liquid which is not pure water, but which instead is water that contains solutes, including fatty substances, apparently released from the protoplasts. The result is that these fatty substances, which lower surface tension, accumulate at the water-air surface along the region of the cut; then, provided there is sufficient access of air, they immediately begin to change in chemical nature and are deposited as suberin in the cell walls and on the surfaces bounding the intercellular spaces (*122*).

If sieve tubes are present in the neighborhood of the cut, the contents of these apparently add greatly to the supply of these fatty substances; furthermore, probably because the reaction of the contents of these sieve tubes is usually relatively alkaline, these fatty substances are supplied under conditions favoring rapid condensation to a suberinlike film. In the potato tuber this suberin deposit may, under some conditions, be seen in sections made 12 hours after the cut surface has been exposed, and it is usually visible after 36 hours; it is probably effective before it is detectable by microchemical methods. If formed at this speed it is probably effective in preventing the entry of microorganisms. In the seakale root it forms very rapidly and is a firm layer within three days, but in some fleshy roots it is much slower in formation. It does not form readily on exposed injuries in the parsnip root, a fact undoubtedly closely connected with the observation that such roots seem to be very susceptible to diseases brought about through chance injuries to the root in the soil. Cut slices of red and sugar beets, although visible suberin deposits are slow in forming, usually remain healthy. What prevents the spread of decay in such tissues is an interesting question.

In most shoots or roots, when upper and lower surfaces are exposed by the process of cutting, it is a striking fact that suberization is usually more pronounced and occurs nearer to the cut surface at the lower cut than at the upper cut. This is only one indication, of the many that will be considered, of the polarity at play in the plant.[4]

In this case the formation of the greater amount of suberin at the lower surface suggests a larger supply of fatty substances present, while the fact that the suberin is nearer the exposed surface suggests that there is a larger quantity of sap which does not withdraw into the wall so rapidly as at the upper end; hence, the air-water surface is nearer the exposed surface of the walls. At the upper end, particularly in a piece of shoot, the sap seems to withdraw into the tissues so rapidly that the deposits of suberin occur in a most irregular fashion. Especially does this occur in the center of the pith and in the outer cortex, that is, in the regions which are farther from the vascular system and thus where the sources of sap are less and the air spaces frequently large. Here the deposits in many cases are so irregular, especially in an internodal region, that these tissues are not sealed from the air by a continuous film; in such cases water loss from the carbohydrate walls continues so freely that the tissues do not decay but dry out and wither.

If the sap supply at the cut surface is adequate to give a continuous film of liquid, then as the fatty substances "cream" to the air-water surface the rapidity and effectiveness of suberin formation is dependent upon various factors. In particular, the free access of oxygen is essential. Thus, if the cut surface is kept swimming in water, the fatty substances leach away and oxygen does not reach them while on the walls, and no suberin deposit is formed. This condition is fatal to successful suberization, and no single factor is so likely as an excess of water to produce decay at the cut surface. This is one reason that justifies the procedure, adopted with many difficult cuttings, of exposing the cut surfaces to air for some time before placing them in the soil.

[4] When questions of polarity are under discussion, there is sometimes the possibility of confusion when the terms "lower" and "upper" alone are employed. The lower surface of an isolated piece of root is, therefore, spoken of as the distal end, and the upper as the proximal. These words are, of course, used in the reverse sense for the shoot, where the upper is the distal end and the lower the proximal.

According to Herklots (*58*), suberization is also aided by a relatively alkaline reaction in the sap, the oxidation of the fatty substances proceeding more rapidly to the alkaline side of pH 6.5. Also, in the case of cut potato tubers, on which most work has been done in this subject, direct exposure to sunlight has often prevented the formation of a continuous suberin deposit at the cut surface, apparently because of a too rapid drying of the sap deposit in the walls and intercellular spaces below the cut (*123*).

Cork Formation

Beneath the continuous deposit of suberin the walls and air spaces which are still saturated with sap are to a considerable extent protected from evaporation. Under these conditions there was found in seakale a region below the suberin film in which, with free-hand sections of the tissue transferred directly from the knife to strong glycerin, the whole tissue appeared translucent, because free from air. In this region a whole series of reactions follow which seem to be initiated as the result of the displacement by sap of the air normally present around these living cells. One of the first changes noticed in seakale cuttings is that starch begins to disappear (apparently being hydrolyzed to sugar); this is accompanied by an increase in the respiratory activity of the cells, and in some cases there is evidence of increased oxidase activity in this region (*17*).

Some of the cells thus greatly depleted in starch become very active in the synthesis of protoplasm and at the same time lose their central vacuoles. Starch is not lost from the outermost dead cells, which are more or less cut off from the active cells by the deposit of suberin on the intervening walls. Within the suberin deposit there gradually emerges a characteristic layer of cells which contain but very little starch and are dense in protoplasm with the nuclei prominent; and in these cells divisions parallel to the surface now occur. Accompanied by and even preceding the appearance of this characteristic layer, occurs the enlargement of many of the cells at right angles to the surface. This is evidently closely correlated with an intake of water, following upon the release of pressure incident upon the act of cutting, but other factors are obviously involved.

The cells thus cut off by this layer, meristematic in nature and without vacuoles, show more tendency for division than for enlargement, so that soon they are flattened between the more actively enlarging cells beneath them and the relatively rigid suberized cells above. This layer continues to divide by walls parallel to the surface; the cells thus formed to the outside vacuolate and develop internal suberin lamellae such as are characteristic of cork or periderm cells. These flattened meristematic cells, which within a few days form a continuous layer across the cut surface below the suberin deposit, function as a cork phellogen, and the permanent protection of the cut surface against the entrance of microorganisms or loss of water is mainly effected by the sheet of periderm produced from this phellogen.

This layer of periderm has certain qualities not found in the original suberin film, which, being merely a thin, rigid film deposited on walls that originally were relatively elastic, is readily broken by the strains set up by changes in the water content of the underlying tissues. If the cells beneath the cut are losing water at a fairly rapid rate, the consequent contraction beneath this semirigid surface leads to deep cracks in the suberin layer; these occur under conditions in which the underlying tissues show but slight tendency toward the accumulation of sap in the intercellular spaces. The result is that air and microorganisms obtain access to the deeper lying tissues under conditions that militate against fresh suberization at the newly exposed surface within the crack, and thus is favored the withering of the tissues, or, with a recurrence of moisture, the resumption of decay. On the other hand, if a sheet of periderm is formed beneath the original deposit of suberin, in the periderm tissue the suberin lamellae of the cells are deposited within them and these are cemented together by a general fatty impregnation of the intervening cellulose walls and middle lamellae (*187*). The result is a layer with very much greater resilience than that of the original suberin film, and one which does not so readily crack under the strains resulting from loss or gain of water by the underlying tissues, and which, because of its depth and composition, is a much more effective protection against the entrance of decay or the loss of moisture.

The same polarity is indicated in the formation of the phellogen at the upper and the lower cut surfaces as is displayed in the production of the original suberin deposit. The phellogen appears first at the lower surface, usually in the neighborhood of the original vascular cambium; from here its formation rapidly spreads across the parenchyma on the xylem side of the cambium, but its formation across the phloem parenchyma is very slow in seakale, and toward the periphery both the suberin layer and the cork phellogen are usually sunk farther into the tissue away from the exposed surface. This is probably correlated with the presence of larger air spaces in this region and with the natural tendency for the level of the liquid retained in these spaces to recede farther from the surface.

At the upper surface of the cutting the cork phellogen appears at a later time and spreads even more slowly toward the periphery. This difference in the rate of formation of the suberin deposit and the cork phellogen at the two ends was more marked in the longer cuttings, but it was evident even in the thin transverse disks, as is indicated by Plate 3, C and D.

Considerable discussion has taken place during recent years regarding the causes controlling phellogen production at the cut surfaces of parenchymatous tissues. Haberlandt's school (*48*, *49*), regarding phellogen activity as one of the manifestations of growth that is promoted by hormones, have assumed two sources for these: (1) The dead or dying cells at the cut surface; and (2) the phloem. Such hormones remain as yet purely hypothetical. There is no doubt that from the dead and dying cells, which become completely permeable, there are released substances which contribute to the supply of fatty substances involved in the original suberin deposit. However, as was pointed out above, such a deposit within a very few hours after the trauma becomes a barrier between these dead and dying cells and the cells which some time later become active as a phellogen. Hence any transfer, across this suberin deposit, of substances that function as hormones and stimulate phellogen activity seems extremely improbable. Furthermore, such substances certainly are not present in normal cases of phellogen activity in a plant that is intact.

The other source of hormones is assumed because of Haberlandt's striking experiments with small disks of parenchyma cut from potato tubers and left under moist conditions (*48*). He found that such disks produced cork phellogen at their exposed surfaces only when they contained a sieve tube. In the potato tuber, as Artschwager demonstrated (*4*), the sieve tubes form a very irregular network throughout the parenchyma of both pith and cortex, so that such isolated disks of parenchyma often contain sieve tubes.

Such experimental evidence, pointing toward the direct influence of sieve tubes upon phellogen production, seems very strong and is in accord with the general position of the phellogen in the normal plant, where it is usually found facing the phloem, although, in the case of epidermal cork, at some little distance from it. The movement of solutes in the phloem is a phenomenon as yet very little understood, but there is considerable evidence to indicate that phloem differentiation, and possibly therefore translocation, usually takes place in a downward direction, both in shoots and in roots. Further evidence of downward differentiation in secondary phloem has been obtained at Leeds in recent years; this seems to suggest that the tendency to downward movement of substances in the phloem is maintained in isolated pieces of tissue, and that polarity, as regards both suberization and meristem formation, is closely associated with this polar organization of the phloem. When, however, very short pieces are cut out, exudation of substances takes place freely from both cut ends, and these are now so close together that the effect of polarity, as shown in the downward transference of the remaining contents of the phloem, is greatly lessened. In experiments with isolated pieces of short internodes of Cucurbita and Coleus considerable evidence has been obtained that the contents of the phloem gradually shift mainly toward the basal end of the isolated segment.

Apart from this suggestion it is difficult to give any explanation of the marked polarity of these isolated pieces of shoot and root save that they are undoubtedly correlated with the polar manner in which these tissues are laid down in the root at the growing apex; the shoot, on the contrary, is organized segment by segment, with vascular differentiation proceeding downward in each internodal segment (p. 6).

It would be unwise at the present state of the knowledge to overemphasize the rôle of the phloem in phellogen activity, particularly in view of some of these experiments with seakale. Disks of secondary xylem parenchyma, which were entirely free from any of the outer ring of secondary phloem, were cut out of the center of the root with a cork borer. The disks of tissue thus obtained produced phellogen freely at all surfaces. Unfortunately, it is impossible to describe this tissue as being absolutely free from phloem, because such disks always contain occasional slender strands which run radially out through the tissue and which are the vascular connections of the original lateral roots that long ago ceased to be active. No evidences of phloem were noticed in these root traces, nor is there any reason to assume that any was present.

In any case, if phloem is necessary, its rôle as a source of "leptohormones" still remains entirely hypothetical; and it is doubtful whether the adoption of a terminology taken from the physiology of animals, the higher ones of which have elaborately developed special organs of internal secretion, without the support of critical experimental evidence derived from plants themselves, does anything except delay the understanding of the problem by employing a phraseology which, with the present limited knowledge of the product and processes concerned, can not have a precise connotation.

The Leeds studies of developmental anatomy have suggested an alternative explanation of the contribution made by the phloem to meristematic activity. The cytological characteristic of the appearance of the phellogen is the emergence of densely protoplasmic cells in a region where previously the cells either had been storing carbohydrates or were swollen with the hydrostatic pressures of large vacuoles, the protoplasm making up but a thin layer around the outside of the cell. The new protoplasts are characterized by a disappearance of the central vacuole along with an increase in protoplasm. Pearsall and Priestley (*104*) have suggested that the behavior of the cell in relation to these processes is closely correlated with the pH of the external sap bathing the protoplast. The maintenance of intense activity in protein synthesis suggests a ready transference of the water thus released by synthetic chemical condensations into neighboring vacuolated protoplasts; it is only over a limited range of pH, in the neighborhood of the isoelectric points of the main constituent proteins, that the protoplast is likely to behave in this manner.

Microchemical reactions show that the suberin deposit, when first forming, is relatively acid in reaction (*58*), as also are the young differentiating cork cells at the time suberin lamellae are being deposited. On the other hand, according to Sachs (*130*) the contents of the sieve tubes usually are relatively alkaline, in many cases actually alkaline to litmus. Thus in a plant which is intact the sap present in the walls and intercellular spaces lying between sieve tubes and the young suberin deposits would show a gradient of hydrogen-ion concentration, across which the phellogen forms. The plastic meristem cells, although compressed by their neighboring vacuolated cells so that they are elongated parallel to the cut surface, never divide at right angles to the surface—that is, by a wall of minimal area, as is usual in a cell at equilibrium with its surroundings (*35*, *165*)—but by walls which lie at right angles to this gradient, as might be expected if the gradient is influencing the synthetic activity of the protoplasm.

This argument can not be carried further in this place, but it has been developed in general relation to the present problem elsewhere (*117*). It at least provides an alternative explanation of the relation of the sieve tube to phellogen activity, and one which permits of an understanding of the circumstances under which the part played by the phloem might sometimes be played by other tissues.

The cut surface of the root is, in the xylem region, interrupted by the presence of tracheids and vessels. These were probably full of sap at the time of cutting, but the sap is rapidly displaced by the air entering the surface with the result that near any xylem vessel present at the cut surface the subsequent air-water interface is found on the flanks of this vessel. Consequently, suberization and cork formation will be found surrounding such a xylem element, the cork cells being cut off toward the empty cavity rather than toward the surface of the cut. In many cases, however, the new cells push through the walls of the vessel as do tyloses, and then rapidly push out through the open ends, so that ultimately the vessels are completely plugged.

APPEARANCE OF THE BUD

Of the process occurring at the wounded surface of seakale cuttings, suberization and cork formation are the ones that have so far been considered because they are associated with the healing of the cut, a necessary factor in successful propagation.

However, these are not the only processes occurring in the early stages following upon the act of cutting. As already indicated, they are associated with an injection of the intercellular spaces near the surface with sap, and this in turn is associated with a loss of starch from the living cells near the cut surface. This disappearance of starch is probably correlated with an increased production of soluble organic solutes, sugars and acids, in the vacuole of these cells, with a resultant increase in osmotic pressure. Certainly many of the cells, in which extension of the elastic walls is not prevented by too rapid deposition of suberin, undergo considerable enlargement, and the free walls markedly round off under the internal osmotic pressure. New cells appear, arising as the result of sporadic cell divisions, or forming serially in a chain from the phellogen cells; these in turn may also swell and round off instead of developing internal suberin lamellae while still regular in outline, in which case they contribute to the formation of callus instead of to the formation of cork. These tissues are certainly to a large extent interchangeable, callus arising under conditions of greater moisture, while the same cells would have contributed to the suberized envelope or to the cork proper if the surrounding air had been drier. These alternative processes have been fully discussed by Küster (*82*) and by Grau (*46*).

In the meristematic cells near the cut surface, at the early stages in development most division occurs in a plane at right angles to the cut surface, the new dividing walls being laid down in a plane parallel to this surface. This is illustrated by the frequency with which mitotic figures are found in longitudinal sections through the material at this stage, while series cut transversely and hence parallel to the cut surface show very few.

The first stages in the appearance of a bud in this material are illustrated in Plate 4. The figures, which are taken from 6-day material, show in line with the cork phellogen a group of meristematic cells which without a doubt originally formed part of this layer. These cells now differ from normal cork-phellogen cells in their shape and in the plane in which successive divisions occur. They are no longer compressed parallel to the surface, and as a result they are larger and their nuclei are completely rounded and lie free in the center of the cells, as occurs in the normal meristematic cells of the apical growing point.

In all probability these changes are the result of a change in the conditions existing in the neighborhood of the original phellogen. Here the meristem cells are compressed against the relatively rigid suberized cells outside by the expanding vacuolated cells beneath. But beneath these uncompressed cells the pressure is released because, as the photographs show, these internal cells are becoming meristematic also. This seems to be the keynote to the emergence of an apical bud, an extension of the tendency to become meristematic from the single cell layer of the phellogen to the living cells within. The result is the development of a small group of meristematic cells, in which the shapes, determined by the mutual pressures, differ from those of the cork-phellogen cells, and in which division no longer takes place exclusively in a plane at right angles to the cut surface. (Pls. 4, C and 5, A.)

On the other hand, the outermost cells of this meristematic group very soon show a definite tendency to divide entirely by walls at right angles, not to the surface of the cut, but to the surface of this group of active cells. This is the method of growth characteristic of the shoot dermatogen, and it soon leads to the development of the typical foliar lobes upon this mass of meristematic tissue. (Pl. 5, E.) At the same time this tendency to become meristematic spreads inward into the tissue beneath this original group. (Pl. 5, B and D.) The cells thus filled with protoplasm and free from vacuoles are surrounded on all sides by the ordinary vacuolated parenchymatous tissue, the result being that these cells become elongated in a direction vertical to the cut surface and so appear to run outward into the lobed mass of meristematic tissue above, forming the first indication of the procambial strands of the new shoot. (Pl. 5, E.) Thus the early differentiation of the new shoot tissues, behind the apical meristem, seems to take place downward, just as it normally does in every subsequent internode of the new shoot; hence the ordinary characteristics of the organization of the shoot apex and of the differentiating shoot beneath it are already in evidence.

Vascular differentiation now proceeds in the procambial strand subtending the newly organized shoot apex; and, as is characteristic of the shoot, this vascular differentiation occurs sporadically here and there along the line of differentiating cells, not in direct connection with the vascular supply of the mother tissue. (Pl. 5, E.) With this, vascular connection is made only later.

The new shoot apex is now characteristically organized and rapidly thrusts itself out from the surface of the mother plant; and the usual active cell divisions, characteristic of internodal growth, proceed along the flanks of the newly differentiating vascular system. It does not seem necessary, therefore, to follow the development of this new shoot system further.

It will be clear from this account that the new shoot organization has developed from the cork phellogen, a point that was reported earlier by Simon (*144*) for similar buds emanating from the callus at the ends of isolated shoots of Populus. Similarly, he described the differentiation of the new vascular elements going on beneath the bud and made clear that such differentiation need not always be preceded by differentiation of clearly outlined procambial strands, for he found that cells of the callus parenchyma lying in the path of the new vascular channel frequently differentiated directly into conducting elements. The general significance of this place of origin of the stem growing point will be considered in a later section, but it seems necessary here to refer to some recent statement of similar cases of bud formation in callus—statements which appear to be completely contradictory to these.

Taylor (*163*) and Graham and Stewart (*45*) described buds arising from the callus at the cut surface of fleshy roots of *Acanthus montanus* T. And. and *Anchusa italica* and referred to them as arising from the vascular cambium. Their statements are supported neither by detailed developmental figures nor by structural descriptions of the bud development. A. *italica* is mentioned again on page 58. Studies upon bud formation in Acanthus were carried out at Leeds some years ago, and it was found that root cuttings of this plant behaved in general like those of seakale. In Acanthus also the meristematic activity of the cells beneath the suberized surface, leading to the production of new cork and callus cells, was found to be most active in the region of the former vascular cambium. But these new cell divisions were found to occur in meristem cells which became flattened parallel to the surface, cut off new cells to the outside, and in all respects behaved as a cork phellogen.

It is true that if one individual cell in this phellogen is considered it may have previously been functioning as a cell of the vascular cambium. But it can not be too strongly emphasized that all experience suggests that there are no fundamental differences between individual meristem cells and that the single cells have the same general meristematic properties whether found in the vascular cambium, the phellogen, the root apex, or the shoot apex. The behavior of the individual meristem cells is determined by the tissue organization of which they form a part, and in the case of Acanthus, beneath the cut surface these meristem cells are functioning as members of a cork phellogen and not as vascular cambium cells; hence it is a definite misuse of terms to describe such tissue as any longer being vascular cambium. On the contrary, these buds seemed just as certainly to arise in the typical cork phellogen as did those of the seakale just described; however, the meristematic activity associated with these buds was not confined to this one layer of cells, for, as was emphasized in connection with seakale, the cells beneath this layer very soon similarly became meristematic and contributed to the further development of the new shoot. Hence, sections of Acanthus as well as of seakale cut through young shoots, still hardly discernible by the unaided eye, show much activity in the tissues behind the phellogen, and it might be easy in many such cases to assume that the shoot had been formed in the inner tissues.

As Schmidt has pointed out (*136*), it is probable that in many cases only the superficial layers of the shoot are actually derived from the cork phellogen, whereas in other cases, as seems to be true with seakale, the entire new shoot except the base is derived from this phellogen layer. This point is obviously of very great importance in the question of the formation and the reversions of periclinal chimeras (*160*).

When disks 1 centimeter each across and 3 to 5 millimeters thick were removed with a cork borer from the xylem region of a large seakale root, it was found that all surfaces exposed became covered with a cork cambium which was capable of forming buds. Capacity to form buds on the sides and root end was also observed on other slices less than 1 centimeter in length, and also in one case upon a piece of a very large root, 5 centimeters thick and 5 centimeters in length, which stood inverted. Centrifuging also aided in the production of buds upon the root end, as was reported by Jones (*69*). The actual formation of the lateral and distal buds seemed to follow the same course as for those forming on the shoot end. Plate 5, C, shows various stages of development of buds on the three exposed surfaces of such a disk.

It must be clearly recognized that different factors are undoubtedly at play, in determining the initiation of these adventive buds, from the factors responsible for their further development. In one disk, 11 millimeters in diameter and 3.5 millimeters thick, 14 days after it had been cut out with a cork borer from the xylem of a main root there were counted 131 separate stem growing points which had arisen in the wound cork cambium. These were distributed as follows: Proximal (shoot) surface, 57; distal, 27; side, 41; and internal (in cork cambium which had formed around vessels), 6. Considering the surfaces exposed in the first three categories, there was roughly 1 bud formed for each 1.8 square millimeters on the shoot end, 1 for each 3.5 square millimeters on the root end; and 1 for each 2 square millimeters of area on the side. This, it will be remembered, was in tissue which contained no true cambium and no phloem at the time it was cut out of the parent root, except such slight traces as might have been present in the remains of the original lateral roots.

Many more buds were initiated on small pieces than on large ones. Except for the one bud that formed on the one large inverted piece, no buds formed on the root end of any cuttings more than 5 millimeters thick unless the piece had been centrifuged. Furthermore, all buds that arose did so from cork cambiums which had formed in either the region of the vascular cambium or the xylem parenchyma; and not a single stem growing point, out of several thousand observed in these seakale studies, came from the phloem parenchyma. This tissue did not seem to possess the power to form buds, notwithstanding the fact that it did, in time, form a cork cambium. It is possible, however, that since this cork cambium was present, had steps been taken to inhibit the formation of buds in the other regions, new stem growing points might have developed in the phloem region. The lack of development of buds in this region seems to be closely connected with the greater development of intercellular air spaces here. In the regeneration experiments of Simon with Populus (*144*), buds were obtained upon the exposed surface of the pith, but their development in these cases was very slow indeed, obviously because the deeper lying meristem differentiation which should lead to the formation of a procambial strand and ultimately end at a functioning vascular supply could not take place. Simon obtained the further development of these buds by cutting a channel through the wood; this permitted vascular differentiation from the apical group of meristem cells to proceed backward to the young differentiating vascular elements associated with the cambium.

Thus it is seen that the formation of an adventive bud seems to require the organization of a superficial group of meristem cells—

the conditions for their functioning approximating closely those that prevail at a phellogen—along with a sap supply which permits the maintenance of this meristematic activity that is subsequently associated with vascular differentiation beneath this superficial group of meristem.

FORMATION OF ADVENTIVE ROOTS

The development of new roots from any isolated root system may take place either laterally or from the wound callus. In Crambe the first roots in evidence after isolation emerge from the normal, lateral surface of the root, when, as is pointed out in the next section (p. 60), they usually appear as branches from the older lateral roots already present in the tissue of the main root. Very rarely in old roots the new roots may emerge laterally from the neighborhood of the cambium of the main axis.

These types of root production are not considered further in this section, but attention is confined to root production from the wound callus which occurs in Crambe as in some other fleshy roots; such adventive roots appear some days after the separation of the root.

If the root piece is sufficiently long, marked polarity is noticeable in the isolated segment. Bud production begins very early and is manifested much more vigorously at the proximal end than at the root end, though under exceptional circumstances (p. 21) buds may appear at the distal end also. In the case of seakale, after about 10 to 12 days, with cuttings kept at about 25° C., vigorous root production from the cut surface was in evidence at the distal end only, and bud production from this end seemed entirely inhibited. The roots usually appeared in a ring over the site of the original vascular cambium. Other roots were occasionally seen to be arising from the xylem region, but no roots emerged from any part of the surface outside the cambium ring. Van der Lek (*86*), considering comparable roots arising upon stems, termed them "wound roots" to distinguish them from the "morphological roots" emerged through a surface that was intact, but this terminology does not seem fortunate, for presumably even wound roots have a morphology.

It will be remembered that when the pieces of root were very short so that distal and proximal surfaces were but a few millimeters apart, both surfaces bore buds freely. On such disks of root no new roots emerged from either surface. Thus from the outset the longer pieces of root differed more in the behavior of the opposite ends, the more activity being displayed at the distal surface; this difference in behavior between the long and the short cuttings evidently increased with time. In the long pieces, during the first few days suberization proceeded more markedly at the distal than at the proximal end, and phellogen activity was likewise more pronounced at the distal end. These differences were also recognizable to a lesser degree in the short slices, but in the further development of the meristematic activities at the two ends by far the greater manifestation of polarity was seen in the long pieces. Although the distal ends of the short pieces formed buds and in the long pieces great meristematic activity was displayed, buds did not form at the distal end, but the new meristems in the longer cuttings were organized instead into root apices. This new development, characteristic of the distal end of a root piece 2 centimeters or more in length, will now be examined in some detail.

The fact that in such material root production appeared to be confined to the distal callus suggests that in such a root a redistribution of meristematic activity continues to take place after isolation, finally resulting in shoot production at one end and root production at the other. Symptoms of such a reorganization of meristematic activity throughout the root piece can be seen in transverse sections through such root pieces, taken after different intervals of time. In the normal root, meristematic activity is mainly, but not entirely, confined to the region of the vascular cambium. Here typical meristematic activity takes place in the region between xylem and phloem. However, growth activity is not confined to the immediate neighborhood of the vascular elements, for interfascicular activity also takes place in the cambial ring, thus the rays keep pace with the increase in the xylem and phloem. In such a fleshy root, moreover, where xylem and phloem are very parenchymatous, cell divisions continue to occur in both the xylem and the phloem parenchyma, and, as has been seen, the regularity of the tissues becomes less and less distinct, particularly in the outer phloem.

After such a root has been isolated, 4-day material shows that near the proximal end the meristematic divisions of the vascular cambium were still strictly confined to the region between xylem and phloem, and in the rays but very slight activity was evident. (Pl. 2, A.) On the other hand, near the distal end (pl. 2, B) it is seen that the meristematic activity of the cambium has extended across the rays as well. Each of these sections was taken about 1 millimeter beneath the cut surface. Plate 2. C, illustrates the state of affairs 2 or 3 millimeters below the proximal surface as seen after seven days. The change in distribution of meristematic activity is here very striking; the activity of the vascular cambium appears to be entirely confined to a region close to the groups of recently formed phloem, which thus comes to be seated outside crescent-shaped rows of actively dividing cells, to the inside of which new groups of short tracheids or vessel elements have already started to differentiate. These are the vascular groups with which are later connected the procambial strands of the buds formed at this end. This section also provides definite evidence of cell division around some of the groups of older vessels—indications that call to mind the cambium that forms in this manner as a normal thing in many fleshy roots like *Oenanthe crocata* L., producing concentric rings of secondary xylem and phloem irregularly throughout the root.

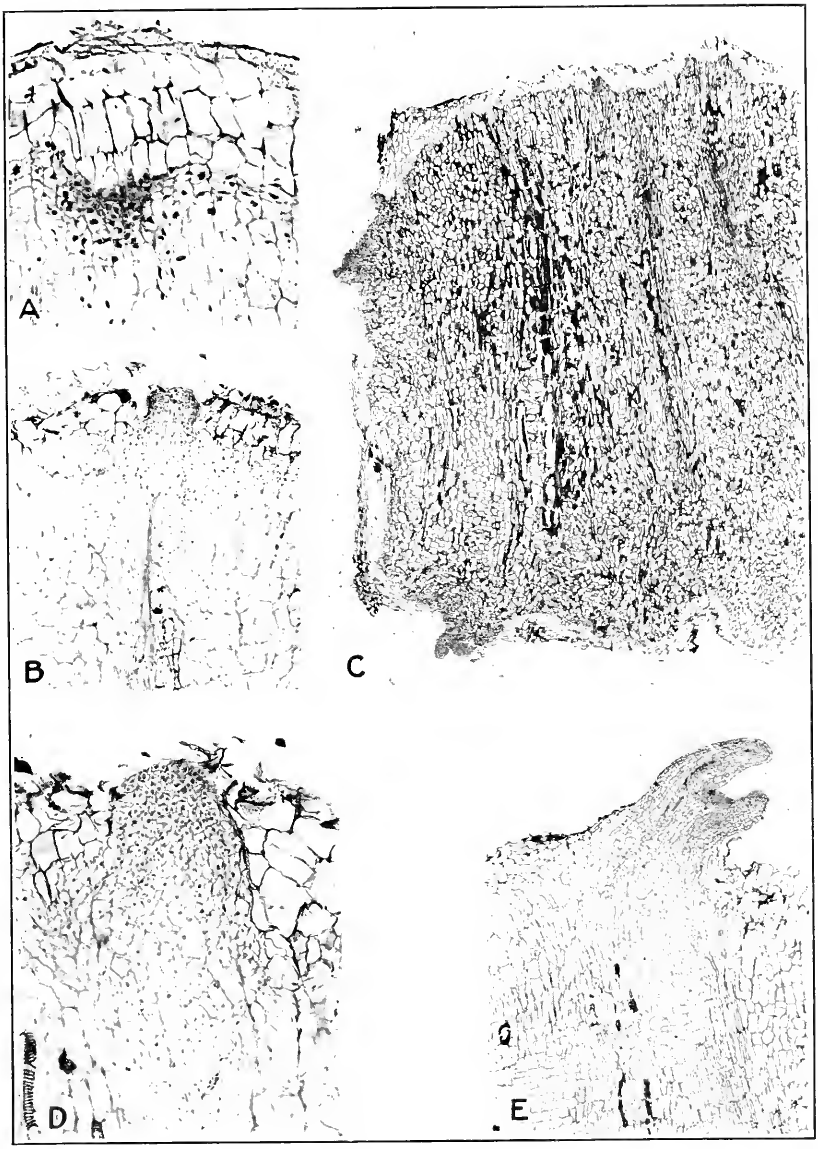
At the lower (distal) end, as Plate 2, D, shows, after seven days similar rings of meristematic activity around groups of vessels are apparent in the interior of the root, but the ring of vascular cambium is here not broken up at all; greater cambial activity has been taking place at this end than before, both between xylem and phloem and across the rays. The products of this activity, to the inside, have differentiated into the short tracheids and vessel segments characteristic of wound wood (p. 33), and to the outside have been cut off cells which presumably must be regarded as phloem parenchyma.

This increased activity of the vascular cambium at the distal end gives, in longitudinal section, a new appearance which is completely missing at the proximal end. In this plane it is seen that the cambial activity has spread around the ends of the differentiated, lignified xylem elements; these old vessels are now covered at the cut surface by the parenchyma cut off during the early stages of the calluslike cell multiplication, and the new cambium differentiates through this parenchyma.

Beneath the suberized cut surface and separated by a parenchymatous semimeristematic tissue two layers of meristem are now stretching; the outer meristem, which forms first, constitutes the cork phellogen, while the inner one is intimately associated with the vascular cambium. The inner line of meristem does not extend into the phloem region at all, but it stretches only across the xylem region. As shown in Plate 6, it seems to merge into the cambium at the side and into the cambiumlike groups which surround the vascular elements scattered within the xylem. This plate also shows that this new cambium has cut off new tracheids to the inside and cells very much like phloem and phloem parenchyma to the outside. Hence, in all respects this new cambium seems to be a regenerated vascular cambium. It is in this mass of tissue, part of it definitely meristematic and part potentially meristematic, extending from cork phellogen to the layer in connection with the vascular cambium, that root initials now originate.

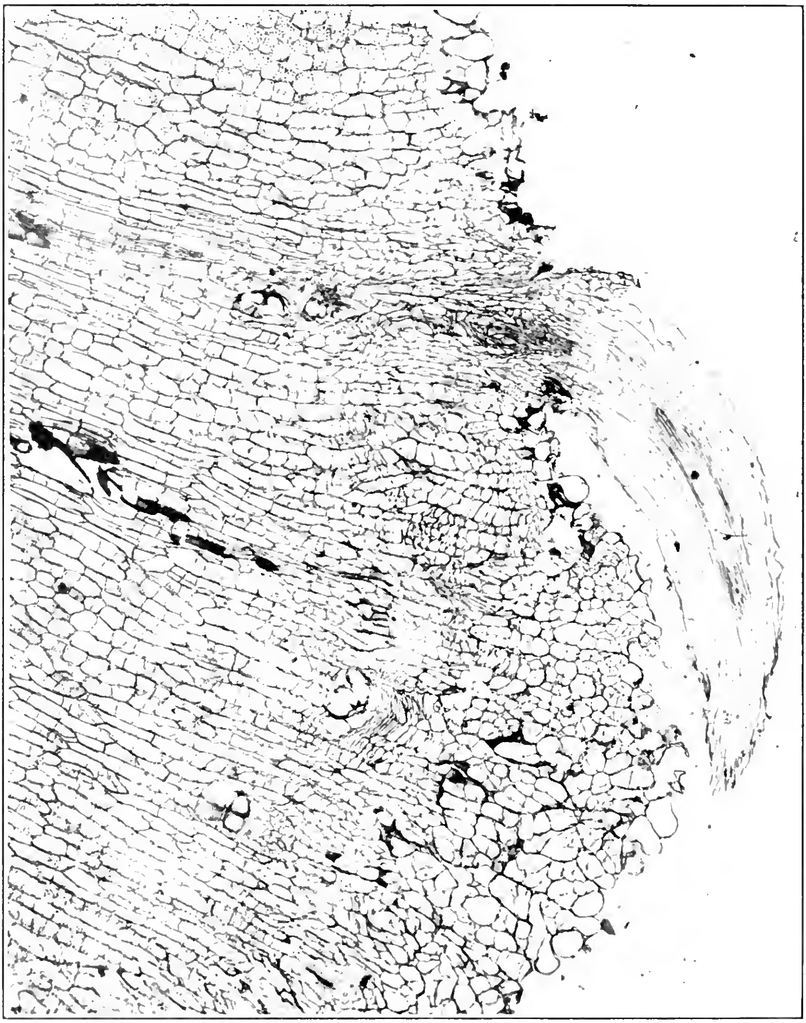
Early stages in root initiation are shown in Plate 7, A–D. In the layer just beneath the phellogen, cells that were already semimeristematic become filled with protoplasm and the nucleus becomes spherical. The phellogen cells themselves, thus released from the pressure exerted from beneath them by vacuolating cells, are no longer so compressed; for a time they remain meristematic in appearance, but they do not undergo rapid division, and therefore there is no increase in the surface of the newly organizing meristem. On the other hand, for several layers within, the cells become meristematic and divide frequently. This happens throughout quite a mass of the subjacent tissue, so that as the root apex becomes more definitely organized (pl. 7, D and pl. 8, B) all the cells throughout a considerable width of tissue appear equally meristematic. Under these conditions there is no indication of a slender ring of meristematic tissue undergoing compression by vacuolated cells within and without, such as is shown by the differentiating bud, so that no procambial strands can be detected, there being only a solid core of meristem of which the inner cells are probably dividing more rapidly than the outer ones (p. 7). Even before the root emerges this core of meristematic tissue has extended down practically as far as the new transverse meristem. However, in every case the roots were seen to arise in the superficial position indicated, opposite either the vascular cambium itself or a strand of cambiumlike tissue surrounding a group of xylem vessels. Hence, as the root organization begins its forward movement, there is a continuity of meristematic tissue between the new cells of the growing point and the newly formed lignified vascular elements of the wound wood, which are connected with the older vessels. In Plate 8, C, the continuity of the vertically extended cells of the vascular cambium with the meristem of the emerging root is very clearly seen, and near the base of the root some of the newly formed xylem elements are visible.

In the case of bud formation at the cut surface the newly organized meristematic apices could not be attributed to any single meristematic



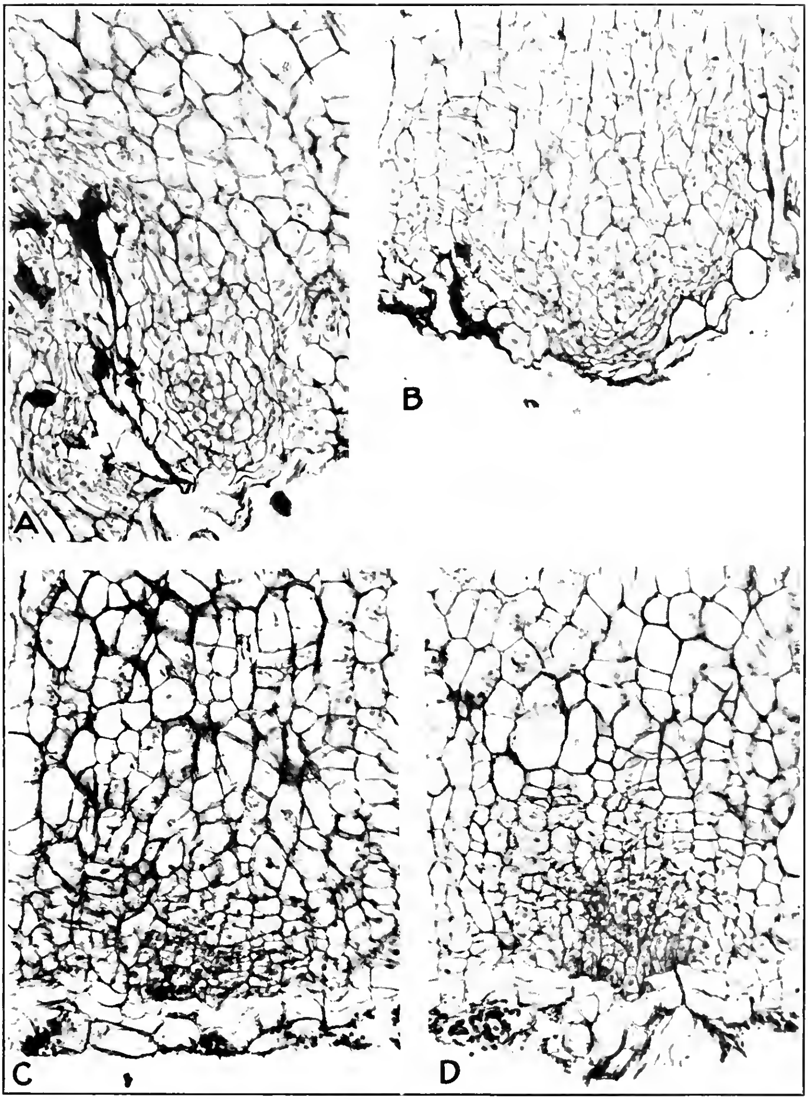
LATER STAGES IN ADVENTIVE-SHOOT DEVELOPMENT ON CRAMBE ROOTS

A.—A bud initial, showing its position beneath the wound cork. Dead cells still filled with starch are shown at the cut surface above the suberized cells. × 90.
B.—A young bud breaking through the wound cork just above the original cambium. × 50.
C.—Longitudinal section through a disk of xylem cut out from the root with a cork borer. A wound phellogen is active on every surface of this disk, and bud initials are also present on each surface. × 15.
D and E.—Stages of bud formation at the proximal surface, illustrating the gradual extension of meristematic activity into the deeper layers of the tissue. In E, procambial strands are differentiating in the two young leaf initials and thence backward into the meristematic tissues beneath the bud. D, × 110; E, × 30.



LONGITUDINAL SECTION THROUGH DISTAL END OF ROOT PIECE OF CRAMBE AFTER 14 DAYS

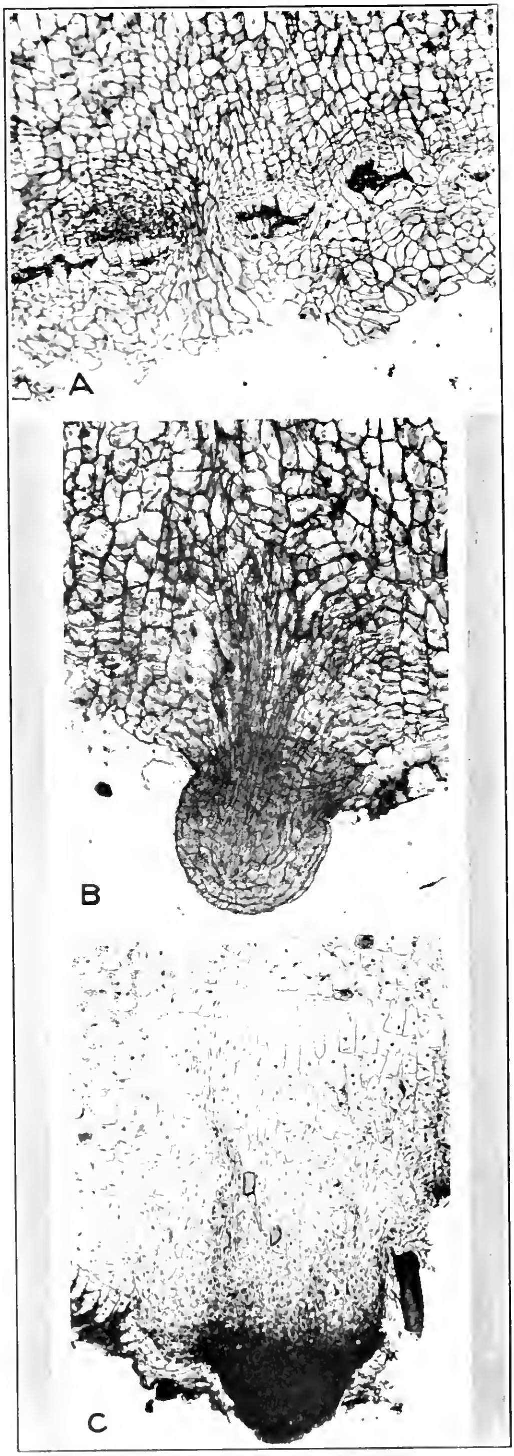
The cork phellogen is visible beneath the suberized layer, and it has formed afresh in the outer layers of the callus, where this tissue has burst through the original suberized layers. Just beneath the position of the original cambium a root has grown out. In the deeper layers of the tissue below the cut surface there can be traced a line of meristematic tissue from which new xylem elements are being cut off toward the inner surface. On the outer side the tissue cut off directly opposite these xylem groups has all the appearance of phloem. This meristematic layer extends only from cambium to cambium. × 50.



FORMATION OF ADVENTIVE ROOTS ON CRAMBE

A–D.—Longitudinal sections through the distal end of root pieces 12 days after isolation. A, On the left note the irregular gash, lined on all sides by phellogen lying beneath deeply stained deposits of suberin. To the right of this gash, just below the cut surface, the meristematic eells of a very young root initial are present. × 110. B–D, Progressively older stages in the organization of a young root initial. × 110.

If these sections are compared with those shown in Plates 4 and 5, it will be seen that at the time and place of initiation the phellogen is less conspicuous beneath the wound cork and seems to take less part in the meristematic transformations associated with the organization of root initials than with shoot initials.



OLDER STAGES IN ROOT FORMATION IN CRAMBE (LONGITUDINAL SECTIONS)

(For explanatory legend see p. 25)

tissue of the original root, though they were clearly associated with the wound phellogen. In this later development of meristematic activity, occurring at the distal end alone, there is unmistakable indication of close correlation existing between root production and the increased meristematic activity associated with the vascular cambium at this end. When the root initial is originally organized the phellogen of the cut surface may form an integral part of its surface layer. But this layer, as is appropriate to a rootcap, ceases to be an active meristematic layer; meristematic characteristics and cell division appear within deeper and deeper layers of the tissue at the wound surface, so that by the time the root is organized and ready to emerge, its inner, actively dividing layers are closely associated with the normal activity of the vascular cambium.

For the internal factors contributing to root formation, therefore, one must look to the factors contributing to this reorganization of meristematic activity which occurs throughout the isolated root. Unfortunately, the anatomical story of polarity, as already indicated, is still largely a matter of speculation. Polarity is bound up with the organization of tissues as a whole, so that to a considerable extent the longer the piece of root employed the more accentuated is this effect.

In the discussion of the relation of phloem to phellogen activity the possible significance of the downward movement in the phloem of solutes essential for meristematic activity has been considered. Such a correlation seems suggested by the increased meristematic activity in evidence at the distal end of the longer pieces, considered in relation to the decreased activity of the vascular cambium at the upper end, and the way in which this diminished activity is confined to crescentlike regions around the groups of phloem. On the other hand, such a correlation between the activity of the phloem and that of the vascular cambium and phellogen is clearly not the only factor concerned, as is shown by the appearance of meristematic activity around many of the internal groups of vessels. As already pointed out, the parenchyma found around these groups is always compressed and relatively free from intercellular air spaces, and to a large extent the distribution of meristematic activity at the proximal end of the root piece could be understood on the assumption that it was necessarily confined to those regions which alone had access to adequate supplies of solutes.

At the distal end, solutes accumulate by the continued polar distributive activity of the phloem, and at this end most of the tissues lying just beneath the cut surface remain charged with sap, so that cambial activity takes place not only near the phloem but also across the rays. Likewise, the entire xylem region, several cell layers back from the cut, becomes more or less meristematic. Between the cork phellogen and the deeper lying meristem which forms subsequently, there is thus left a layer of semimeristematic parenchyma in which

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EXPLANATORY LEGEND FOR PLATE 8

OLDER STAGES IN ROOT FORMATION IN CRAMBE (LONGITUDINAL SECTIONS)

A.—Distal end after 12 days, showing manner in which proliferation of callus forces tissue out through the barrier of suberized cells. Where this happens very little meristematic activity is seen, though a phellogen is reorganizing outside the suberized layers in several places. Above the suberized layer, on the left of the section, a root initial is organizing. × 50.
B.—Distal end after 12 days, showing a root apex emerging from the cut surface. × 100.
C.—Distal end near emergence of a large root (very deeply stained). Behind this a connection can be traced between the meristem cells of the root apex and the vascular cambium of the main root. On the right of this line of meristem cells new xylem elements are differentiating. × 60.

the intercellular spaces are small and injected and in which therefore, the supply of water and solutes are adequate for growth. This tissue, as it multiplies, expands with considerable pressure against the barrier of suberized cells at the surface. Often here and there the inelastic film of suberized and dead cells is broken, with, as an immediate result, the emergence and exposure of the parenchymatous cells within, which "flow out" through the gap as a large-celled, loose, spongy tissue in which the large intercellular spaces fill with air. As Plate 8, A, illustrates, where such rupture occurs, organized meristematic activity ceases. The meristematic cells of the newly organizing root initials as well as those of the shoot initials were always seen to be confined to the region of tightly packed cells lying beneath this still-effective suberized barrier. Neither roots nor shoots were seen to arise opposite breaks in the cork cambium.

The development of shoot apices and root apices taking place at the cut surface of Crambe has been considered. It is clear that internal factors, which are at present far too little understood, determine which, if either, of these types of meristematic activity will be manifested. Shoot meristems appear first, arising in the layer of actively growing cells which lie nearest the cut surface (cork cambium) and under conditions which allow the supplies of food necessary for the continued development of this meristem to reach it through the underlying tissue. This activity may appear at either cut surface, anywhere over the cambium or the xylem parenchyma, and possibly under special conditions even over the phloem parenchyma. At the distal surface only, and later in time, special conditions of meristematic growth prevail, in which activity is so organized that the inner layers of the meristematic tissue are the more active in division, and from an early stage in their development these are closely associated with the meristem which is giving rise to differentiated xylem within—the vascular cambium. Thus, from an early stage, the dense core of the root meristem is organized in contact with the vascular stele. The cells in the outer layers, previously phellogen, whether from lack of food or from some other reason fail to divide actively, and contribute instead to the rootcap of the new structure. Hence, a type of organized meristem emerges from a meristematic matrix that, had it been given certain other internal correlating factors, would have utilized the same energy in the production of a shoot.

That meristematic tissue with such potentialities for shoot production should actually give rise instead to root initials can not be a matter of surprise, in view of the fact that many years ago Beijerinck described the transformation of a typical shoot apex into a root meristem (*11*). Lateral shoot buds appear at intervals along the root of *Rumex acetosella* L. and under normal conditions often grow out into new shoots. But if a piece of this root system is isolated and placed vertically in damp soil, while the upper buds grow out into shoots, in some cases one or more lower bud initials will grow on into roots. Plate 9, C, shows such a root; at its base rudimentary bud scales can be seen. It was obtained in experiments at Leeds, in which Beijerinck's original observations were confirmed by Edmondson.[5]

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[5] EDMONDSON, W. E. THE TRANSITION FROM BUD INITIAL TO ROOT IN RUMEX ACETOSELLA. Leeds. 1925. [Unpublished thesis.]

Furthermore, in a later section (p. 78) a case is illustrated where shoot and root apices were organized very close to one another within the parenchyma near the cut surface of a root of *Cichorium intybus*. Here shoot and root meristems must have originally come from groups of cells that were as close to one another as the phellogen and the deeper lying meristematic layer in the distal callus of the root of Crambe.

Root production seems to be much more closely related than shoot production to the normal activity of the vascular cambium. It is, therefore, perhaps worth emphasizing the striking parallel that exists between the normal vascular cambium, which cuts off more cells to the inside, and the root meristem, which is the more active on the inner surface, facing the stele (*117*). The general conditions governing these two forms of growth activity, the adventive shoot apex and root apex, will be reviewed once more and from a wider angle, in the next section, where a wider range of phenomena is discussed in connection with their organization during vegetative propagation.

THE GENERALIZED PROBLEM

ADVENTIVE SHOOTS

Apparently the apical organization and development of the shoot always proceed along the lines indicated in the preceding sections so that to this extent the problem of the origin of new shoots in vegetative propagation is always the same. But the organization of the tissues in which they may arise varies greatly and the problem of the development of adventive shoots is different, when such structures develop upon isolated leaves or stems, from the problem as outlined above for seakale, and it is still more distinct in the case of buds arising on uninjured roots.

In all cases it is necessary to distinguish clearly between the further development of a meristematic shoot apex, dormant but already organized, and the initiation of such an apex as the result of developmental changes brought about by special conditions such as the isolation of a portion of the plant. Shoot apices may be present in a dormant state upon any portion of the plant, either shoot or root, and the extremely diverse manner in which such primordia commonly occur in different species makes it difficult to use the qualifying term "adventive" (or "adventitious") with a precise connotation.

Koch (*78*) described very fully the process of branching in the flowering plant. He showed that the meristematic "anlagen," constituting the lateral buds, in the case of some water plants as well as occasionally in inflorescences, may appear upon the apex, even before the subtending leaf initials appear. On the other hand, in practically all trees and shrubs the new lateral buds arise some time after the leaf initials have appeared at the growing point, at a time when the internodal development taking place makes these axillary meristematic groups distinct in origin from the meristematic tissue crowning the apex. It would probably be incorrect, therefore, to define, as Hofmeister (*61*) did, an adventive bud as any bud which arises on the axis, without genetic meristematic connection with the original apical meristem, since such a definition would undoubtedly include as adventive a number of axillary buds that have emerged in their regular place, in acropetal order, upon the shoot. On the other hand, it is equally difficult to draw a clear distinction between different buds based upon their order of development, or even upon the relation of injury to their emergence, as Sachs (*131*) did. Thus, every axillary bud is the result of the activity of a little axillary cushion of meristem which is usually located in the axil between stem and leaf, but which may be on the surface of either leaf or stem near the axil. The activity of this meristematic mass is not always exhausted by the formation of a single bud; in many plants, as a regular thing, other buds may be organized in series near the first buds, either above or below them, or on the flanks. Such buds were termed "Beiknospen" by Sandt (*134*), who investigated the phenomenon very fully. This employment of the prefix "bei" needs to be borne in mind because of the possibility of confusion arising from the entirely different way in which the term "Beiwurzeln" is employed (p. 60).

These "Beiknospen" may be originally present in the leaf axil; at other times, as the result of injury or removal of the original single bud, an exactly similar behavior of the axillary meristematic cushion may cause their production; in the latter case, such "Beiknospen" would be termed "adventive" by most workers. Similarly, the dormant bud which emerges long after the usual time of appearance as determined by its acropetal position on the axis may be the further development of a meristematic cushion which had been left on the axis at almost any stage of development between that of an original group of meristematic cells and that of a definitely organized shoot apex.

Again in many plants, including *Cardamine pratensis*, *Atherurus ternatus* [*Pinellia tuberifera* Ten.] (*52*) and *Torenia asiatica* L. (*185*), buds regularly arise upon leaf veins or petioles, and thus, though a feature of the plant's normal development, certainly fall into the category of "adventive," using this term as originally defined by Du Petit-Thouars (*34*), who classified as adventive all buds not terminal or axillary. These leaf-borne buds, however, do not coincide so well with the remainder of his original definition—buds arising later in life than the normally situated structures.

However, if the term "adventive" were employed with shoots as De Candolle (*20*) and many later workers have employed it for roots—only roots arising on other organs than roots being described as adventive—these shoots, emerging normally from leaf tissue, and therefore from a portion of the shoot, could not come into the category of adventive, while all the numerous cases in which shoots appear upon the root as a part of the normal development of the dicotyledon root system (*11*) would be included.

There seems, therefore, only one of two alternatives to be followed in the practical employment of the expression "adventive." In dealing with such diversely organized structures as flowering plants, either the term must be loosely employed or all but a single group must be ruled out. If the term is used in a general sense, there seems little reason to depart far from the original practice, in which any shoot organization appearing in any position other than terminal or axillary, or which appears at some relatively late stage in development, may be termed "adventive." On the other hand, if a precise use of the word is desired, it must be restricted to the numerous cases where, as the result of the abnormal conditions resulting from injury (as in cutting propagation), buds arise in tissues which, whether meristematic or permanent, were not previously organized as meristematic shoot apices.

This strict delimitation of the term would make possible precision in its use, but at the cost of some practical convenience; consequently for the present the writers will continue its use in the general sense, because the problem with which they are concerned is the development of buds in a portion of the plant isolated for vegetative propagation. Such buds may emerge from dormant apical shoot organizations, from meristematic cushions in which this capacity to organize so is latent or only partly indicated at the moment of separation, or, as was seen in the case of seakale, such buds may be an entirely new development resulting from the injury and isolation which is essentially a part of cutting propagation. As has been said, the main differences between these types appear in the organization of the tissue upon which the shoot apex emerges. For that reason it will be convenient to discuss first the development of shoots upon shoots and then of shoots upon roots.

SHOOTS UPON SHOOTS

Monocotyledons

In the great majority of cases when isolated portions of shoots are used for vegetative propagation, the system isolated includes some normal axillary buds and the shoot system of the new plant arises from these. In the case of most monocotyledons this is practically the only possible method of vegetative propagation, as permanent tissues very seldom again become meristematic in such plants, while in the older regions of the plant meristematic tissues are found only in the node and the basal portion of the leaf.

In a number of monocotyledons isolated portions of shoot or root will produce a type of cork at the injured surface, but, as Philipp (*108*) pointed out, this cork is usually different in nature from that characteristic of the dicotyledon. Instead of the original permanent tissue differentiating into a phellogen layer which then remains active for an indefinite period, the cells in one or more layers beneath the cut surface divide into a limited number of segments by walls parallel to the cut. None of the individual cells thus formed function as meristematic phellogen; all become suberized, and in many cases no further cork formation takes place beyond that occurring in this single layer. In other cases, cells adjacent to those which first divided, in turn become active and divide, so that quite a depth of suberized cells may be produced; but the seriation of the blocks of cells in the tissues, as seen in section, is determined by the arrangement of the cells in the original parenchyma in which the divisions occurred, and there is no continuous serial order of the cells such as results when a common phellogen is responsible for their formation. In the origin of the adventive shoots of *Crambe maritima* it was clear that the new shoot organizations arose from the meristematic cells of the phellogen. No layers with such meristematic potentialities appear during the process of cork formation in most monocotyledons, and it is not surprising that no case has so far been described of adventive-shoot formation from the cut stem or root surface in any monocotyledon where cork formation is of this type, which is termed by Philipp "etagen" cork, in contradistinction to the ordinary "initial" cork of the dicotyledon.

In some monocotyledons typical phellogen activities are displayed, as are also certain other characteristic cambial layers. It is from such members of the Liliaceae alone that bud formation has been described, either from the stem callus, as in *Aloe arborescens* var. *frutescens* Link (*69*), or from the root callus as in Dracaena and Dioscorea. In several species of Lilium, in Ornithogalum, and in *Pinellia tuberifera*, bulbils, or shoot organizations, appear upon the leaf-lamina base as a normal thing, very much as similar structures occur within the ovary in Allium. Such buds are, of course, commonly employed in propagation. Furthermore, in the case of many fleshy monocotyledon leaves in which the basal meristem normally persists for some time, when these leaves are isolated, adventive buds appear at or near the cut surface, arising from cells lying just below suberized cells, near the point of injury. Examples are Haemanthus (*43*), Drimia (*44*), and Sansevieria.

Whether the shoot organization is already present in the plant at the time of separation, or forms at the leaf base only after injury, its development follows the same regular course.

The leaf initials arise as folds, almost completely surrounding the meristematic apex; beneath these the internodal tissues subsequently differentiate as cylinder within cylinder, while at the base of each differentiating internode, root initials are developed in connection with the procambial ring. Apparently, in every case in the monocotyledons new roots are formed in connection with such nodal or leaf-base buds, in the new shoot itself; hence at a very early stage the new individual is completely independent of the parent plant. Of course, in many cases where the stem is used as a cutting, roots arise from the main axis as well as from the base of a developed bud. This point will be briefly considered in the next section. Schubert (*137*, *138*), in his account of the propagation of monocotyledons by cuttings, gave a list of species in which propagation has been successfully effected from leaf bases.

Dicotyledons

In the dicotyledon, meristematic tissues are much more widely distributed, their regeneration from permanent tissues occurs very much more frequently, and therefore the modes of organization of adventive buds are much more numerous.

Again, the most familiar example is that in which an axillary bud, left in the isolated portion of the shoot, continues to develop and produces the shoot system of the new plant. The development of such an axillary bud conforms in general very closely to the story of the development of adventive buds from wound callus in Crambe. Such an axillary bud constitutes merely an "anlage" of meristematic tissue in the axil of the leaf. Contemporaneously with its development, the differentiation of the internode in the axis above was proceeding; the procambial strand of a leaf situated higher on the axis ends just above the insertion of this bud, so that just beneath it in the procambial ring occurs a gap which is filled with parenchymatous, nonmeristematic tissue. When the procambial ring differentiates into a vascular system, the xylem and the phloem differentiate downward, this tendency to differentiate passing obliquely around the sides of the branch gap and the leaf gap, which still remain parenchymatous. However, when the organization of this axillary shoot apex continues, the parenchymatous tissue becomes traversed by the procambial strands of the new branch system. In this process of differentiation the vascular elements appear as separate osmotic systems during the early stages, and only gradually link up, by backward differentiation, with the sides of the leaf gaps and with the leaf traces below. Thus the organization of this lateral shoot apex takes place from the surface inward as in other cases, the process sometimes here extending over several months.

ADVENTIVE BUDS UPON THE STEM

If no buds are left upon the detached portion of the axis, in very many cases new buds can be formed. Frequently these arise from small shoot apices which were lying dormant, perhaps in the axil of a scale leaf or as accessory buds ("Beiknospen") at the base of an original bud. The recent extensive observations of Plett (*109*)[6] show that even when such initials are absent new buds may still be formed. Thus, out of 401 species examined, 38 species produced buds upon internodal cuttings, of which 27 also produced roots. On the other hand, although only 11 species formed buds alone, 67 species produced roots alone, indicating a relatively greater tendency for root production than for bud production. In such internodal cuttings, where no remnant of the original bud base and meristematic cushion is left, the new buds usually arise from the wound callus. Plett found that the following species produced buds in this manner: *Rudbeckia laciniata*, *Boltonia latisquama*, *Centaurea calocephala f. aurea* Dry., *C. rupestris* L., *Scabiosa arvensis* L., *Salvia sylvestris* L., *Physostegia virginiana*, *Solanum nigrum*, *Lycopersicum esculentum*, *Nicotiana tabacum*, *Sinningia purpurea* Hort., *Acanthus montanus*, *A. mollis*, *A. spinosus*, *A. longifolius* Tour., *Fittonia argyroneura*, *Passiflora caerulea*, and *Cleome spinosa*. He found that in *Maurandia lophospermum*, Begonia, and several Peperomias the buds arose in the cortex, in Torenia probably from the epidermis, in Apocynum they appeared as lenticellike outgrowths in the cortex, and in Lysimachia from one epidermal cell.

Failure to obtain buds from internodal cuttings obviously can not be accepted as conclusive, as repetition under other conditions might lead to success. In the absence of the anatomical details in each particular case of failure it is difficult to determine in just what stage of the regenerative process the failure occurs.

In a few cases Plett[6] found that buds arising at the distal end of such cuttings were in direct vascular connection through the internode with the roots arising from the basal end; thus in such cases the original cutting remains an integral part of the new vegetatively propagated plant. In the great majority of cases, however,

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[6] PLETT, W. UNTERSUCHUNGEN ÜBER DIE REGENERATIONSERSCHEINUNGEN AN INTERNODIEN. 46 p., illus, Hamburg, 1921. [Unpublished Inaug. Diss. Auszug published 1921 (*109*).]

this does not happen, the establishment of the new shoots as independent plants being conditional upon the development of roots from their bases.

In an experimental study upon callus formation occurring in woody twigs such as Populus, largely dealing with the influence of external factors, Simon (*144*) paid some attention to anatomy. He pointed out in the first place that the somewhat vigorous callus production taking place in these shoots in moist air differed greatly between the two ends of the shoot. At the upper (distal) end he found the callus to be very irregular in form; the vascular cambium seemed to take a comparatively minor rôle in its formation, and the callus was developed through the repeated division of the cells of all the living tissues at the exposed surface, including the pith. However, the cells in the neighborhood of the vascular cambium were the most active in the process. At the lower end the callus was much more regular in appearance, being in the main a mass of tissue cut off by the vascular cambium. This layer continued to form downward into the callus, arching inward toward the wood and cutting off both parenchyma and wood to the inside; to the outside it formed less tissue, all of it parenchymatous in nature, while still farther out a certain amount of calluslike growth and division occurred. At both ends near the outer surface of the callus could usually be traced a meristematic layer which was forming new cells, mainly toward the surface, thus contributing to the formation of the callus or cork, according to the relative humidity.

Simon noted (*144, p. 363–364*) that buds arose from the superficial cells of the callus if they formed in the early stages of its development, but when a well-marked meristem or phellogen had appeared near the surface, then the buds arose from the neighborhood of this meristem. His results are, therefore, closely in line with the observations upon Crambe.

Simon (*144*) also found that according to the conditions under which the shoots were maintained the position of the buds could be modified. Thus, while usually buds appeared at the distal callus and roots at the proximal, if the formation of the distal callus was repressed by some means and the shoots were supplied with plenty of water, numerous buds arose at the basal callus; inverted cuttings formed a few buds on the proximal callus. If, however, the distal callus, now the lower, stood in water, then 75 per cent of the cuttings produced buds from the proximal callus. Tittman (*166*) had similarly shown for Populus that with repression of the distal callus and with the removal of the axillary buds, adventive buds could be obtained from the basal callus.

Plett[8] noted in his extensive experiments with internodes that, although the roots almost invariably appeared at the proximal end of the cutting, the buds seemed to arise anywhere. Only in *Salvia sylvestris* and *Acanthus mollis* were the buds confined to the distal callus; in several species, including *Boltonia latisquama*, *Physostegia virginiana*, and Nicotiana, most buds were formed upon the basal callus. Gravity and light seemed to produce very little effect upon the position and production of these buds, but moisture exerted a

[8] See footnote 6 on p. 31.

very marked influence. Plett concluded, as Simon was inclined to do before him, that the marked polarity shown by regenerating roots as compared with the irregularity in position of the regenerating buds might be connected with the relatively different origins of roots and shoots. As has been seen, the buds are almost always exogenous in origin, but the roots, which are generally associated with the vascular cambium or pericycle, are endogenous. Plett, therefore, suggested that the inner tissues of the plant seem to be constructed with a polarized, axial symmetry, whereas the outer layers and the tissues of the callus are not polarized.

From the standpoint of anatomy the differences in the distribution of buds and roots upon these internodal cuttings become somewhat clearer. A considerable amount of unpublished work has been done at Leeds upon internodal cuttings, partly upon herbaceous plants such as Helianthus, Phaseolus, Vicia, and Pelargonium, and partly upon woody plants such as Acer, Ligustrum, and Malus. In all this work the general truth of Simon's conclusion (*144*) has been confirmed, namely, that the callus usually differs in origin as well as in behavior at the opposite ends of isolated pieces of shoots. (Pl. 9, A, B.)

At the proximal end of shoot cuttings, from the very early stages, the vascular cambium is intimately associated with the production of the mass of new tissue. The cushion of tissue thus arising at the base is largely formed by the cambium ring through tangential divisions which cut off cells to the inside of the cambium, and just as also occurs in the normal activity of the cambium many of the cells thus formed differentiate into short tracheids or vessel segments. Frequently at the base of the shoot the wood thus formed differs materially from the normal wood in having fewer vessels and more parenchyma cells; the vessel segments formed are also shorter and have a narrower lumen. This type of wound wood may be limited to the very base of the shoot or it may not be detected at all; it corresponds very closely with the type of wood frequently formed in the neighborhood of ringing wounds (*79*, *156*). In addition to this "dynamic wedge," as Hartig called it (*54*), the cells of the cortex, phloem, wood parenchyma, and pith may undergo a certain amount of extension and division, giving rise to a tissue which is carried outward along with the main mass of tissue arising from the cambium.

The fleshy roots of Crambe, as indeed of many other types of isolated root pieces, show much less indication of such cambial activity at the equivalent, i. e. distal end. As has been already brought out, while callus was formed vigorously over the whole surface, the cambium playing the leading rôle in such activity, it was formed rather by divisions parallel to the surface and not by divisions with the orientation usual in the cambium.

At the surface of the callus formed at the basal (proximal) end of the shoot cutting, even though arising originally from the vascular cambium, another meristematic layer soon emerges just below the surface. In this layer, as has been seen, divisions take place by walls parallel to the surface, giving rise either to cork or to callus. From this phellogen buds frequently appear; in the callus of a fleshy root such as seakale, this layer is visible very early and bud production is both early and widespread. On the other hand, as was originally pointed out by Stoll (*154*) the origin of the roots can usually be found in the neighborhood of the layer of dividing cells which is still genetically connected with the vascular cambium; they are thus in most cases distinctly endogenous.

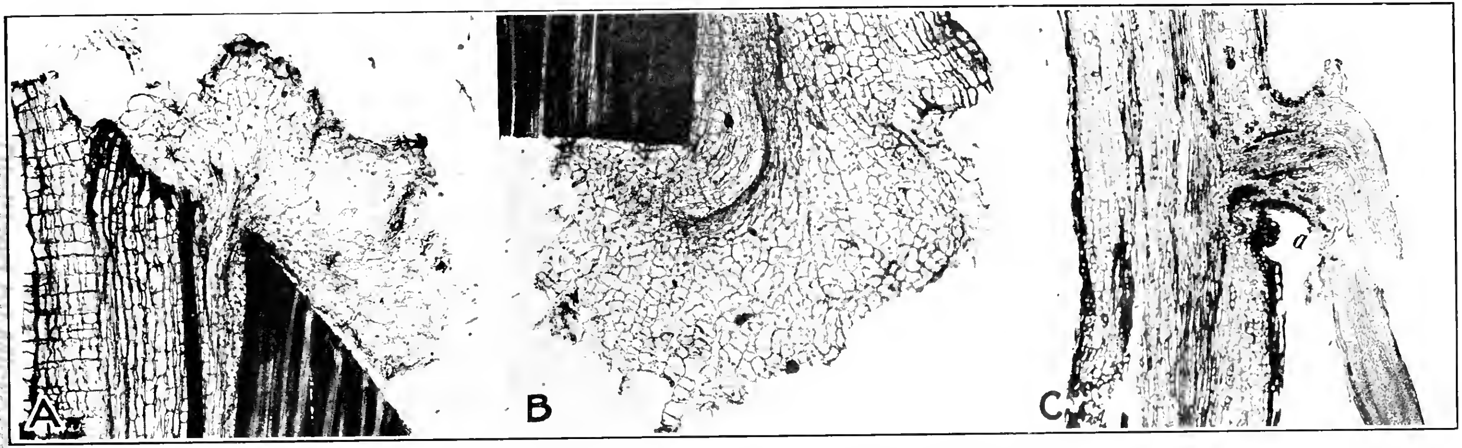
At the distal end of the shoot cutting in many cases callus production is very slight indeed. If, as commonly happens, the atmosphere around the cut surface is not saturated with moisture, the sap originally injected into the intercellular spaces beneath the cut surface seems to be rapidly absorbed, so that the original fatty deposits which give rise to suberized membranes are very irregular and often well below the surface. Even if the air is saturated and callus does appear, as Swingle (*162*) and several others have pointed out, this is less than that arising at the basal end. More important in this connection, however, is the fact that while the tissues adjacent to the cut may give rise to a callus by cell extension and multiplication, the production of a regular "dynamic wedge," such as that occurring at the basal end by the tangential divisions of the cambial cells, has never been observed at the distal callus, although the individual cells in the region of the cambium may be especially active in the process of callus formation. The new cell divisions are irregular and occur mainly by walls parallel to the cut; hence none of the new tissue can be regarded as the direct result of the normal activity of the vascular cambium. A further important point is the fact that none of this tissue shows any tendency at this stage to differentiate into xylem, as it does at the basal end; in internodal shoots of woody plants practically no xylem formation, either of the nature of wound wood or of the normal type, has been observed in the Leeds experiments to occur at the distal end of woody cuttings.

In the distal callus a phellogen also appears near the surface, and in this buds may arise. Xylem formation in this callus then occurs in connection with the procambial strands of these new buds as they differentiate. Hence, although buds may appear at the surface of the callus formed at this end of the cutting, or occasionally at the other end as well, in view of the fact that the origin of new roots seems to be so closely connected with the activity of the vascular cambium it is not surprising to find roots confined to the basal end.

Likewise, in cuttings of fleshy roots, as has been said, cambial activity at the corresponding proximal end of the cutting is also less than that occurring at the distal end, and root production from this end of the root piece very seldom if ever occurs from such wound tissue. Anatomy thus seems to throw a little light upon the more extensive distribution of buds in these isolated shoot pieces as compared with the localized production of new root initials.

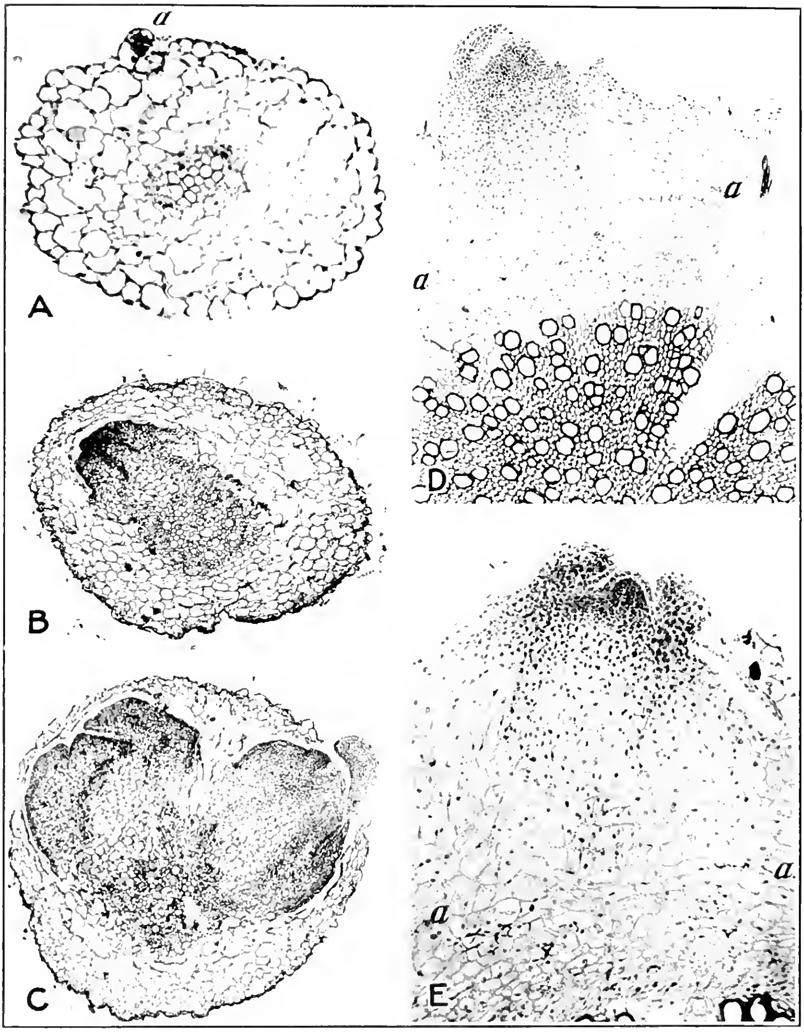
ADVENTIVE BUDS UPON THE HYPOCOTYL

The dicotyledon seedling usually bears its first buds in the axils between cotyledons and epicotyl, but in a number of seedlings buds frequently occur upon the hypocotyl, below the cotyledons; in many other cases, though buds do not normally occur in this position, they may also be formed upon the hypocotyl as the result of special treatment (*10*, *18*, *81*). Extra-axillary buds occur here far more fre-



A and B.—Longitudinal sections of the callus from an isolated internode of Forsythia: A, Distal; B, proximal. In A, the callus has formed mainly by transverse divisions and subsequent cell proliferation of the parenchymatous tissues of pericycle, phloem, and cambium. In B, note the active part taken by repeated longitudinal tangential divisions of the cambium, so that new tissues, with differentiating tracheids, have been cut off toward the xylem. The cambium lies around an arc of tissue so produced. This characteristic cambial activity does not occur at the distal end. × 55.

C.—Longitudinal median section of a root of *Rumex acetosella* through a lateral structure which, although originally organized as a shoot apex, owing to experimental treatment has grown forward as a root apex. At the base of this lateral root small scale leaves are visible (*a*). The apex, however, now has a typical root meristem. × 30.

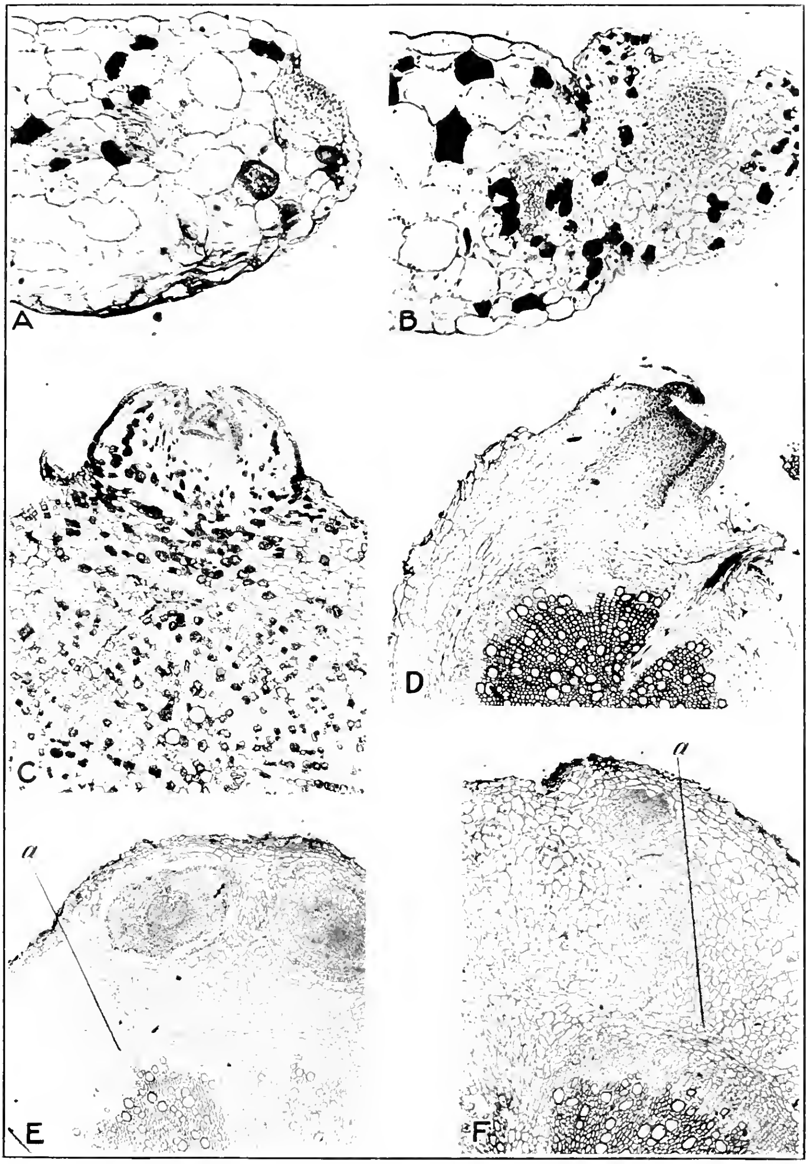


FORMATION OF ADVENTIVE SHOOTS ON HYPOCOTYLS AND ROOTS (TRANSVERSE SECTIONS)

A.—Hypocotyl of *Linaria macedonica*. The beginning of an epidermal bud is visible at *a*. × 100.

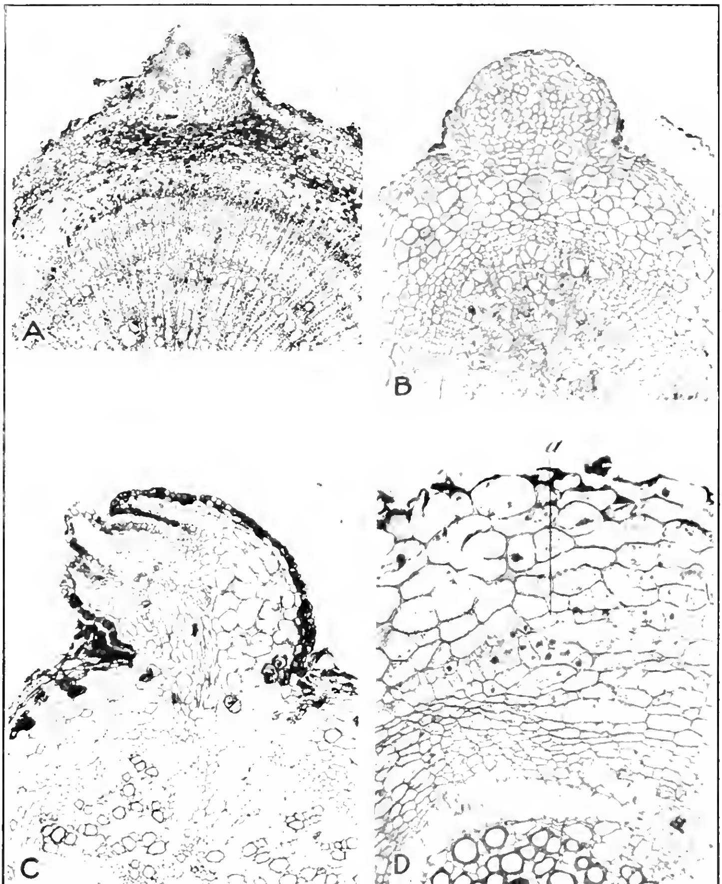
B and C.—Seedling roots of *Convolvulus arvensis* just below the hypocotyl showing stages in emergence of endogenous buds. The procambial strands in these buds are differentiating backward from the apex of the buds toward the vascular system of the root. The buds lie opposite protoxylem groups in the root. × 15.

D and E.—Root of *Linaria repens*, showing exogenous buds arising in the neighborhood of branch roots. Especially in E, the centripetal development of the procambial strands is clearly indicated. In each of these sections, in the region just below the bud, a gap is visible in the primary endodermis of the main root. The endodermis is each case is indicated by the arc *a*, *a*. × 100.



ADVENTIVE SHOOTS ON ROOTS AND LEAVES

A and B.—Leaf of Bryophyllum, showing adventive buds forming near the margin of the leaf: A, very early stage (× 70); B, with first leaves developed (× 80).
C.—Root of *Epilobium angustifolium*, showing polyderm at the surface of the root (the primary cortex is exfoliated) and a bud arising from just within the polyderm. This bud actually arises near the base of a branch root. × 45.
D.—Root of *Linaria repens*. The procambial strands of the exogenous bud lying to the left of the old branch root have differentiated through the primary cortex back to the region of the vascular cambium. × 50.
E and F.—Root of *Helenium autumnale*, variety Riverton Gem, showing buds differentiating in the primary cortex outside the endodermis (*a*). These buds lie just within the exogenous phellogen. E, × 50; F, × 35.



A.—Old root of *Teucrium scorodonia crispum*, showing a bud arising in the neighborhood of the pericyclic cork, unconnected with any branch root. × 25.

B and C.—Root of *Euphorbia cyparissias*, showing stages in the emergence of a bud from the pericyclic phellogen. Traces of the exfoliated primary cortex are still visible. In the older bud (C) the procambial strands have differentiated backward until connection is practically made with the vascular ring of the root axis. The position of these buds is independent of the emergence of branch roots. B, × 80; C, × 60.

D and E.—Root of *Anemone baldensis*. In D, a very young bud initial is developing in the pericycle. The endodermis, a narrow layer of cells just outside the bud, is indicated at *a*. In E, taken from another point upon the same root, the endogenous bud has broken through the cortex. Note its position in relation to the protoxylem (*a*). D, × 100; E, × 40.

FORMATION OF ADVENTIVE SHOOTS ON ROOTS (TRANSVERSE SECTIONS) quently than on the epicotyl, while, as will be seen later, adventive buds upon the root system just below the hypocotyl are of still more frequent occurrence. It is probable that factors governing the appearance of buds upon the hypocotyl may be very similar in nature to those determining the appearance of buds upon roots, and it may be profitable to bear in mind the facts presented in this brief section in connection with the data dealing with the production of buds upon roots.

A number of plants bearing such hypocotyledonary buds are considered in Beijerinck's monograph (*11*) where references to the earlier literature will be found. A few examples may be discussed to illustrate the points that have already emerged from anatomical study, but many more data are still needed.

Anagallis and Linaria show examples of hypocotyledonary buds which are epidermal in origin. (Pl. 10, A.) But though the first cells to become meristematic are epidermal, as Van Tieghem (*169*) pointed out long ago, the position of the buds seems to be determined by the arrangement of the vascular system. In diarch roots the branch roots appear in four rows, one on each flank of the two protoxylem groups, and when buds are found they appear in the same position. In the hypocotyl, similarly, the buds are formed opposite the primary vascular rays, though with the few scattered buds usually found it is difficult to say whether they form in four rows. Although the first cells to become meristematic are those of the epidermis, the subsequent growth of the bud involves the gradual extension of this meristematic tendency into the inner tissues. First the cells of the cortex lying just inside the superficial meristematic group and then the cells of the endodermis and pericycle become meristematic, and thus a path of meristem is formed all the way between the vascular system and the new superficial meristem. In this meristematic sector the procambial strands differentiate, and from these the vascular elements. Thus the vascular connection with the main stele is made in the way that throughout has proved characteristic of the shoot organization. This centripetal meristematic differentiation below the original superficial meristem of the hypocotyledonary bud was clearly described by Van Tieghem. It is illustrated for the exogenous buds upon the root of *Linaria repens* Mill. (pls. 10, D, E; 11, D), where an exactly comparable form of differentiation is displayed. The exogenous position of these buds, in view of the existence of a functioning secondary endodermis around the stele within, is a matter of considerable interest. Unfortunately, there are not sufficient data to discuss this problem in reference to the hypocotyl; it must suffice to point out that the buds are similarly exogenous in the root of Linaria, whereas in *Convolvulus arvensis* L., where the buds arising upon the hypocotyl are clearly figured by Beijerinck (*11*) as being endogenous, those arising on the root are likewise endogenous. (Pl. 10, B, C.) This difference in bud position on the root is discussed in a later section, and for the present it can only be assumed that the same factors operate in determining the position of hypocotyledonary buds as those determining the position of root-borne buds.

Boodle (*14*) illustrated a similar centripetal differentiation of the vascular supply of the adventive leaves arising upon the hypocotyl, or seedling tuber, of *Cyclamen persicum*.

ADVENTIVE BUDS UPON THE LEAF

The appearance of buds upon isolated leaves is obviously only a special case of their appearance upon shoots. Although the usual position in which buds occur upon the shoot is generally in the axil of the leaf, cases have been described where they appear elsewhere on the axis as a regular feature, notably upon the hypocotyl. Similarly, buds may occur normally upon the leaf. A number of such cases among the monocotyledons have already been referred to. Although there is usually not the same persistent meristematic base in the dicotyledon leaf, buds here also occur upon the leaf, always upon the upper surface. Usually they are to be found at the junction of the leafstalk and lamina, as in *Tolmiea menziesi* Torr. and Gray (*129*), *Cardamine pratensis*, *Radicula nasturtium-aquaticum* (*Nasturtium officinale*) (*52*), and others. In Bryophyllum they are found in the serrations, apparently at the margin of the leaf, but actually still on the upper surface. (Pl. 11, A, B.) The shoots thus found normally upon the leaf show various degrees of development, from that of a well-organized shoot apex to but a small group of meristematic tissue in the case of Bryophyllum. In any case the further development of this meristematic apex usually depends upon the separation from the parent plant of the leaf bearing it, and as a result very extensive series of experiments upon the internal correlating factors controlling growth have been carried out with such material, particularly with the leaves of Bryophyllum (*41*, *90*). Such studies have, however, dealt but slightly with the anatomical aspects of the problem.

When leaves without buds are isolated, in many cases adventive shoots are formed upon the isolated structures. The most extensive series of such experiments recorded in the literature appear to be those of Lindemuth (*88*, *89*) and Stingl (*153*). These have been summarized by Janse (*66*) as follows: Species whose leaves give neither roots nor buds, 47 and 43 per cent; species giving only roots, 52 and 46 per cent; and species giving buds with or without roots, 5 and 15 per cent. according to Lindemuth and Stingl, respectively.

Probably the difference between these percentages as given by the two different workers is mainly due to the fact that Stingl included 20 species of monocotyledons in his trials, and Lindemuth only 1, and monocotyledons never seem to form roots alone, their adventive shoots always being accompanied by roots.

When bud initials are thus organized anew, they practically always appear toward the basal (proximal) end of the isolated leaf system, usually at the base of the leafstalk or at the junction of petiole and blade. Winkler (*185*) described in some detail the widespread production of buds over the upper surface of the leaf in *Torenia asiatica* L., regarding their extensive distribution in this case as a striking phenomenon; but even here the buds do not occur near the margin at the apex. Nevertheless, there seems to be considerable latitude in their place of appearance, and Winkler's attempt to create different categories of buds according to their position does not seem to help in the understanding of this widespread distribution. In cases where veins were cut through in leaves lying on moist sand or other suitable propagating material, buds also frequently arose at the end of the vein, just above the cut.

The details of the development of adventive shoots arising on the leaf are particularly well known for Begonia from the work of Regel (*124*), Vöchting (*175*), Hansen (*52*), Sachs (*133*), and Hartsema (*56*). In this case the bud is often described as arising from a single epidermal cell, but this description may be misleading; it is only true in the same sense that in the development of the bud upon the hypocotyl (p. 35) the bud may first arise in one epidermal cell. This cell divides first by a wall parallel to the surface of the leaf, but Hartsema pointed out that in *Begonia rex*, although this division occurred by the third day, in some cases by the second day some of the mesophyll cells below had already divided.

No noticeable increase in size takes place in the epidermal cell, but changes in cell contents are continuous, and Hartsema observed protoplasmic streaming in sections of living leaves mounted in sugar solution. These movements were associated with a gradual increase in the amount of protoplasm present and with a shifting of the moving stream of protoplasm from a rotation around the wall to a circulation in and out of the center. With these phenomena was observed a transference of the nucleus toward the center of the cell, a movement suggesting an increase in the relative density of the cytoplasm. Cell divisions continued until ultimately the original epidermal cell, with its outline still clearly discernible, was seen to be filled with a mass of small, densely meristematic cells. To this extent the new shoot is the outcome of a single cell.

But now the cells of the mesophyll beneath this active epidermal cell were seen to be changing in the same way and likewise becoming meristematic; it is this differentiation which permits of the subsequent linking up of the new shoot with the vascular system of the original leaf. The possibility of the occasional complete formation of the new shoot from one cell is not excluded, because, if one of these groups of meristematic tissue formed within a single cell should be isolated from the leaf, it is probable that under some conditions it could provide itself with a root; usually, however, in the leaf the cells lying between the epidermis and the vascular bundle cooperate in the production of the new shoot, which may thus depend for a time upon the roots produced upon the vascular system of the leaf in a manner described in a later section (p. 64).

It is essential to distinguish sharply, however, between the mesophyll cells being active in the formation of the vascular connections at the base of the new shoot, and such inner tissues taking part in the organization of the growing point itself. In most cases this distinction seems to be of little value; yet in the case of periclinal chimeras and certain variegated plants, which may also be, in many respects, periclinal chimeras, this genetic constitution of the growing point assumes a great significance. The junior writer has given a review of the subject of graft hybrids (*160*).

Beinling (*12*), in describing the formation of buds upon isolated leaves of Peperomia, where the buds arise from cells of the ground parenchyma close to the cut surface of the leafstalk or the leaf blade, pointed out that these buds when quite young are often cut off by cork from the tissue of the parent leaf and in that case never become linked with the vascular bundles of the leaf. When this occurs, the cells giving rise to the new shoot are always closely associated with the phellogen appearing beneath the cut surface.

Similarly, in *Torenia asiatica* the adventive shoots are described by Winkler (*185*) as commencing their origin with changes in a single epidermal cell. In fact, in all cases referred to in the literature of adventive shoots arising upon leaves there is nothing to modify the general impression that such shoots appear as exogenous structures, their linkage with any existing vascular system always being the result of subsequent differentiation beneath the original superficial meristem. In this respect, as reference to page 64 will show, there is a very clear distinction between the mode of origin of adventive shoots and that of roots upon leaf cuttings.

An interesting point about leaf cuttings is their apparent inability in many cases to form shoots, though they may root and remain alive for many months.

Although a number of isolated cases are known, the majority of species of dicotyledons which readily produce adventive shoots upon leaves are to be found in the families Droseraceae, Crassulaceae, Begoniaceae, and Gesneriaceae (*11*). As Küster pointed out (*81*), almost all these plants possess a very succulent type of leaf, the mesophyll consisting largely of a dense mass of vacuolated parenchyma, with comparatively small intercellular air spaces. The ability to form leaf buds is probably intimately associated with this type of structure, because when such leaves are isolated and held under moist conditions the injury may readily be followed by the injection of these small intercellular spaces with sap, at first directly in the vicinity of the injury and subsequently elsewhere through the injection of air spaces in the neighborhood of veins which become overcharged with sap. Under these conditions, circumstances may readily become favorable (1) for the increased nutrition of epidermal or subepidermal cells, with a tendency for them to become meristematic, and (2) for the subsequent differentiation of the tissues beneath these epidermal groups and hence their linking up with the main vascular supply.

In the majority of leaf petioles, while the intercellular spaces are frequently smaller and injection may more readily occur, Lohr (*91*) found that secondary changes were much more marked. Cambial activity in the vascular bundles was strikingly manifested, in many cases a closed ring of cambium and vascular tissue being formed where normally only a broken circle of bundles would have been present. Phellogen activity was often seen also, sometimes occurring sporadically at the bases of trichomes, but in other cases as a continuous epidermal, subepidermal, or deeper seated layer, in petioles where normally phellogen does not occur. This observation, coupled with that of Beinling (*12*), as to the source of adventive shoots in Peperomia and with the close connection seen to exist between phellogen and adventive shoots, should further emphasize the need for caution in the interpretation of negative results as regards adventive-shoot production in leaf-propagation experiments. To take a specific example, Lohr (*91*) reported negative results as regards bud production with the leaf of *Iresine lindeni*, though the leaf rooted in one month and an abundant phellogen activity was evident after two months. On the other hand, Lindemuth (*89*), who noted particularly the cell enlargement shown in the lamina of this same type of leaves (from 10 by 12 cm. to 12.5 by 15 cm.), obtained buds. Hence as long as tissue can be stimulated to such superficial activity as phellogen production, it seems unwise to give up hope of obtaining buds. *Camellia japonica* is frequently cited as another good example of a leaf that will produce only roots, but Janse (*65*) noted an exceptional case where buds were also obtained.

Furthermore, when roots are obtained, the roots themselves may provide the future buds. Vöchting (*176*) described the following interesting case: In *Thladiantha dubia* Hook. a tuberous swelling appeared at the proximal end of the root which had developed from the leaf, and from this swelling a bud arose. Winkler (*186*) depicted a similar case, two buds being obtained from the base of an isolated tendril of *Passiflora caerulea.* The tendril coiled spirally and became woody, and then a white calluslike swelling developed at the base of the tendril; after about three months a root grew out from this swelling, and many months later the buds also appeared upon it.

In this connection it is perhaps worth while drawing attention once again to some old observations published by Agricola in 1716 (*1*). The leaves of apple, cherry, walnut, and chestnut were taken, their cut ends were covered with wax, and the bases of the leaves were buried to a third of their length in moist earth. The leaves gradually decayed until little but the midribs remained. But at the base of the midrib of some of the leaves a swelling developed from which roots arose, and in a year a small shoot likewise appeared. Attempts made at Leeds to repeat these observations have not been successful, but the soil-moisture and oxygen conditions under which success is possible are evidently quite limited, and, as has been emphasized, the difficulties in the way of propagation tests lead the writers to attach much more importance to recorded positive experimental results than to unsuccessful attempts at repetition.

The suggestion put forward above as to the anatomical factors contributing to success in obtaining the formation of buds throws some light upon a number of somewhat isolated observations upon propagation from cotyledons. Smith (*148*) carried out a very extensive series of observations, confined solely to this type of leaf, and in no case observed an adventive shoot, although the cotyledons frequently increased in size considerably beyond their normal dimensions, and roots developed in many cases. On the other hand, Küster (*81*), with three genera of Cucurbitaceae (Cucumis, Cucurbita, and Luffa), and Hill (*60*), with Cyclamen, obtained adventive shoots from cotyledons, although normal leaves of these genera have furnished no known examples of adventive shoots. In these four genera the cotyledons contain smaller intercellular spaces than do the later formed assimilating leaves, and it is probably in this fact, rather than in their greater food reserves, that the explanation for the more ready production of buds in the cotyledons is to be found. Thus, the production of buds upon hypocotyls is increased rather than decreased by the removal of the cotyledons. Likewise, with isolated green leaves left in the light in the propagating frame, there is no reason to think that supplies of assimilates fail or that development is hindered for lack of food. On the contrary, active growth may be proceeding in the leafstalk (*94*), while the leaf tissue is gorged with starch, and roots may have long since appeared; but still in many leaves buds are not produced. Consideration of these special cases of adventive-shoot production upon leaves seems, therefore, to strengthen the standpoint already arrived at as to the importance in shoot production of the existence of internal conditions favorable for the growth of a superficial meristem and for the subsequent differentiation of the vascular system beneath it.

SHOOTS UPON ROOTS

Apart from the normal axillary buds and those originating in close connection with the axillary meristem, adventive buds occur comparatively rarely upon the shoot. In only a few families are such structures produced upon isolated leaves, and their regeneration upon isolated pieces of shoot is comparatively rare; likewise it has been seen that their normal appearance upon the shoot elsewhere than in the leaf axil is very rare. Buds are more frequently found normally upon the hypocotyl than upon the epicotyl, and they can likewise be more readily induced experimentally upon the hypocotyl. In accordance with this general distribution, buds upon root systems are relatively of much more common occurrence; in many species they occur normally and in many others are more or less readily induced by wounding; hence with dicotyledons, methods of propagation making use of root-borne buds are commonly practiced.

Beijerinck's comprehensive monograph (*11*) contains most of the known facts as to the distribution of root buds, to which very little could be added as the result of more recent work. However, an attempt will be made here to examine from the standpoint of anatomy the facts as to the occurrence and distribution of root-borne buds. From this standpoint it immediately becomes clear that the whole problem of adventive-shoot formation upon the root is governed by internal structural factors which differ from those concerned in adventive-bud production on the shoot.

THE INFLUENCE OF ROOT ANATOMY

In a previous section (p. 7) events occurring behind the growing apex of the root were considered up to the point where a central stele, bounded by an endodermis, has become distinct from the cortex; the latter is bounded to the outside by a few layers of cells, the radial and transverse walls of which are free from intercellular air spaces, and the outermost layer of which usually functions as the piliferous layer. The distinction in structure and function between stele and cortex is thus very sharp in the root. It was pointed out that within the stele the vascular elements, xylem and phloem, are differentiating. The walls of the xylem elements are composed of lignified, permeable cellulose; within them there is no semipermeable membrane, and undoubtedly the aqueous sap present in the xylem moves freely into the walls of all the surrounding tissues up to and including the inner tangential walls of the endodermis. But, as has been brought out, the flow or diffusion of the sap outward along the radial and transverse walls of the endodermis is prevented by the Casparian strip.

Since the endodermis forms a continuous cylinder, one cell thick, extending from the meristematic apex of the root up to the region of the hypocotyl, it may be visualized as a chimney in which the bricks are represented by the living protoplasts and the intervening mortar by the Casparian strips. (Fig. 1.) A striking feature brought out by microchemical work upon the root is the marked consistency with which the endodermal protoplasts adhere to the Casparian strip. They may be pulled away from other portions of the wall by plasmolyzing agents, or in dead material by strong acids, but even under such conditions it is only with great difficulty that the protoplasts can be separated from the Casparian strip, and in life it seems doubtful if they are ever so separated (*119*). The result is that, although the vascular system and parenchymatous tissue of the stele may be charged with water and solutes under pressure (when the absorbing system of the root is at work), this system does not leak, because it is

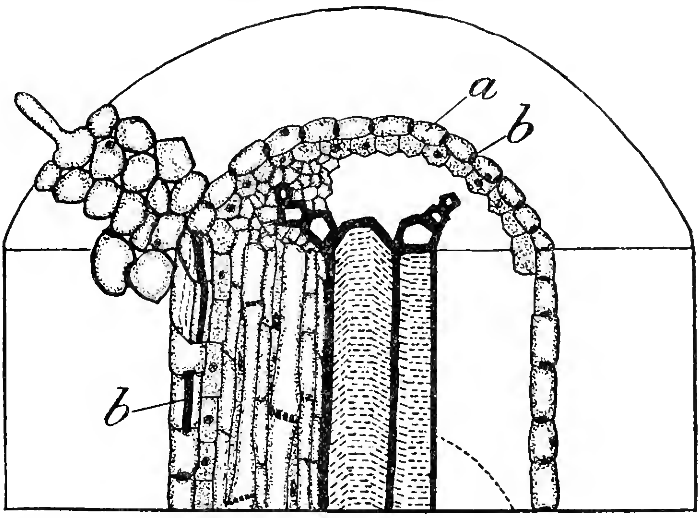


FIGURE 1.—Diagram of a young root as seen in transverse and median longitudinal section. The vascular elements are inclosed within the cylinder of the endodermis (*a*). Sap may move outward from the vascular elements until the endodermis is reached; then further outward movement is stopped by the fat-impregnated Casparian strip (*b*), which is continuous around both radial and transverse walls of all the endodermal cells

bounded by this endodermal chimney in which both flow and diffusion outward through the walls are completely prevented.

Since transference of water and solutes between cortex and stele takes place only across the living protoplasts of the endodermis, movement through these protoplasmic membranes will be practically confined to diffusion. This molecular movement through the walls will be largely determined by the osmotic gradient between the inner and the outer tangential wall. With the inner wall containing the xylem sap and the outer wall presumably containing nothing more concentrated than the soil solution, the movement of water through the protoplast would normally be inward and not outward. Of the actual movement of solutes through the endodermal protoplast, as yet nothing is definitely known. The subject has recently been discussed elsewhere in some detail (*142*). It seems safe to say that there is little likelihood of loss of solutes from stele to cortex occurring through these protoplasts.

Thus it is seen that in the young root a set of conditions is present which must greatly affect the question of propagation. Although the living cells of both cortex and stele may potentially be capable of meristematic growth, the solutes from the vascular supply, which alone can furnish the necessary nourishment, are almost completely confined within the stele, and hence any flow of sap capable of displacing air from the intercellular spaces is not possible outside the stele. The result is, as Tetley (*164*) pointed out, that growth activities in the root are confined within the stele and that the cortex of the root is singularly uniform in character throughout all the flowering plants.

Within the stele, the cells abutting upon differentiating vascular elements themselves in turn tend to undergo the same fate, and it is the cells farthest from the vascular elements—the pericycle—that longest retain their meristematic character (*117*). These pericylic cells seem to play a very important part in propagation.

In the growing root, as the nutrient supply available becomes capable of maintaining more meristematic activity than is represented by the terminal apical group, additional divisions take place in the pericycle by tangential walls, the number of layers of meristematic cells being thus multiplied. These regions practically always lie opposite the protoxylem, except in diarch roots or in those in which mucilage canals are developed just outside and exactly opposite the protoxylem groups. Van Tieghem (*169*), who first made this generalization, pointed out that it suggested a spatial relationship between this special meristematic activity and the xylem and phloem, of such a character that, when the radial sectors occupied by these adjacent tissues in the root were not too wide, the position of this extra meristem (opposite the protoxylem) left it contiguous to both xylem and phloem. On the other hand, in the diarch root, where xylem and phloem lie in radii 90° apart, a comparable position is obtained for the meristem only when it lies between the radii passing through the centers of xylem and phloem. Hence, while in roots containing more than two sets of bundles there are as many extra groups of meristematic activity as there are protoxylem groups, in a diarch root there are four groups, one on either flank of each group of protoxylem.

In the young root these extra groups of meristematic activity are usually soon organized as local root apices, which may grow out almost at once or which may lie dormant for some time.

Endogenous Buds on Young Roots

In some cases these extra meristematic groups arising in the pericycle are differently organized from the outset and develop as shoot apices. In these cases the distribution of such buds follows the same laws as Van Tieghem (*169*) found for the branch roots. Beijerinck (*11*) cited *Prunus domestica*, *Convolvulus arvensis*, and *Ajuga genevensis* as having buds of this type in the young root, and he described them as replacing root initials; in certain other cases (*Sisymbrium alliaria* Scop. and *Anemone sylvestris*) buds of this type occur in the same vertical series as do the lateral roots. Buds arising in this manner are definitely endogenous in character, though such position of origin is usually regarded as characteristic of root initials; however, the difference between shoot and root can not be based upon their position of origin, for buds may be either endogenous or exogenous, while in the next section roots that are exogenous will be described. The difference between roots and shoots, whatever their origin, lies in their organization as growing structures.

The endogenous buds of *Convolvulus arvensis* and *Anemone baldensis* L. are shown in Plate 10, B and C, and Plate 12, D and E. It will be seen that the emergent bud with its leaf initials, even after it has burst through the cortex of the root, is still quite unconnected with the stele of the parent root by any vascular strand. Such a connection differentiates independently in the axis of the new shoot structure and then by a further centripetal differentiation becomes attached to the vascular system of the stele. In *A. sylvestris* and *A. hupehensis* the buds apparently always arise in the pericycle, no cork having been seen in these roots; in *A. baldensis* and *A. japonica* pericyclic cork occurs, and the buds sometimes originate in this and sometimes in the pericycle before the cork appears.

ROOT BUD SPORTS

The practical employment in propagation of such endogenous buds provides an opportunity of sometimes obtaining bud sports which, in general, can be understood from the standpoint of anatomy. In the shoot organization, as was pointed out, the dermatogen and one or more inner layers of cells divide continually by walls laid down at right angles to the surface. The result is that throughout the whole shoot a certain number of superficial layers covering stem, leaf, and flower are all the products of the activity of these same superficial meristematic layers. This mode of growth renders possible the existence of graft hybrids, which are periclinal chimeras, a "skin" of one parent incasing a core of the other. Also in many variegated plants, even though the inner and outer tissues may be of the same species, they may still be essentially this same type of periclinal chimera (*9*).

As long as these plants are propagated by stem or leaf cuttings, their character remains essentially the same. But whenever root propagation is adopted, if the new buds arise endogenously, a new situation is displayed. As has been seen, the sequence of events occurring at the root apex does not readily permit of the isolation of a series of superficial layers of meristem that form the whole superficial envelope of the root, because in every case the most external layers soon cease to be meristematic. But usually the activities of a fairly distinct dermatogen (or, better, protoderm) (*50*), through repeated divisions by walls at right angles to the surface, has given rise to the piliferous layer. Within these superficial tissues the pericycle, which is often regarded in histogenesis as the outermost layers of the stele, certainly has no connection with any of these external layers, and it is from this pericycle that the cells arise which form the dermatogen of the root-borne bud. Naturally, therefore, any special characteristics possessed by the "skin" layers of the plant are entirely missing from this endogenous root-borne bud, and the shoot system developing from it shows only the characteristics of the "core." Hence, where such buds can be obtained from roots, the student of graft hybrids or variegation has a method of analysis that may prove helpful in many cases. But it is necessary to ascertain anatomically that the buds are definitely endogenous in origin; as shown later in discussing certain root-borne Compositae buds, more variation is possible in this character than is usually suspected.

Even if the buds that emerge from a root system are exogenous in origin, however, it should presumably be the exception rather than the rule for the superficial layers of the new shoot to have any direct genetic connection with the surface layers of the parent shoot, since, in most cases of root-cutting propagation, the roots used will have had an endogenous origin (p. 60). As a result, none of the root system will have any genetic connection with the superficial region of the old shoot. Furthermore, even if the original root used as a cutting formed part of the true seedling root system, in which case the primary cortex possesses superficial layers that may be genetically similar to the superficial layers of the shoot, when the branch root system arises from this main root axis the cortex of the branch root will be formed by a meristem arising entirely from the inner layers of the main root. Only exogenous buds regenerated from the main axis of such a seedling root would therefore be likely to repeat in the new shoot any special characteristics possessed by the superficial layers of the parent shoot.

Endogenous buds arising in the pericycle at a relatively early stage of root development are comparatively rare; usually in the young root the first indication of additional meristematic activity in the pericycle is the organization of additional root initials. As the root grows older, but still at a comparatively early stage, another form of meristematic activity becomes apparent in the stele of the dicotyledon: in the parenchymatous or procambial tissues still persisting between phloem and xylem repeated divisions occur by tangential longitudinal walls and thus a vascular cambium comes into existence.

As this layer is carried outward by the differentiation of the xylem elements recently formed to the inside, it is completed as a continuous ring by a series of tangential divisions occurring in the pericycle cells lying just outside the protoxylem groups. The vascular system of the root is now completely rearranged as regards the internal correlations likely to influence the future meristematic activities of the pericycle. As pointed out previously, the sap found in the xylem is usually at a very different hydrogen-ion concentration from that in the phloem. There is no doubt that in the young root, because of the character of the solutes that they contain, both xylem and phloem influence directly the behavior of the pericycle (*117*).

But after the vascular cambium has formed, a continuous sheet of meristematic tissue cuts off the xylem with its characteristic solutes from the pericycle without. Internally, the latter layer is now bounded partly by phloem and partly by parenchymatous ray tissue and no longer abuts upon any protoxylem. Hence it is not so surprising to find that from this time on the meristematic activities of the pericycle are different in character. After secondary thickening has commenced in the root, no further root initials originate in the pericycle. On the contrary, in this layer a phellogen frequently becomes active and cuts off a cork layer beneath the endodermis. This fact seems quite in keeping with the marked correlation, previously referred to (p. 16), between the proximity of phloem and the maintenance of a phellogen.

Endogenous Buds and Pericyclic Phellogen

It has been seen that in very many cases shoot meristems are closely associated with phellogen; hence it is not surprising to find that the pericyclic phellogen occasionally gives rise to buds. Examples are *Teucrium scorodonia crispum* and *Euphorbia cyparissias*, which are illustrated in Plate 12, A–C. Other examples that have been noted at Leeds include *Ailanthus glandulosa* and *Coronilla varia.* In *Statice limonium* L. the buds also arise in the phellogen but near the point of origin of a branch root. In this connection see also the note as to the behavior of the thicker portions of the root of *Thladiantha dubia* (p. 49).

Buds arising in association with a pericyclic phellogen are obviously still endogenous in origin, but they frequently do not appear to be so, a fact that explains many misconceptions in the literature. Frequently, by the time the pericyclic phellogen has formed, the endodermis has undergone changes that make it completely impermeable to all outward movement of water and solutes. In any case, with the formation of a sheet of periderm all transference of materials between stele and cortex is precluded. As this stage is reached the cortex of the root becomes brown and withered. The stele continues to increase in girth as a result of the activity of the vascular cambium, and the withered cortical tissues, unable to adjust themselves to the increasing strain, crack and flake away, exposing the endodermis itself as a cracking layer; thus the cork phellogen from which the buds emerge appears to be the superficial layer of the root. Misled by this fact, Wilson (*183*) recently described the buds arising upon the roots of *Roripa austriaca* Spach. as exogenous in origin, but it is important to correct this misstatement. The phellogen of this root, from which buds arise, is pericyclic in origin, and the buds are endogenous. Below will be described several types of phellogen, which, being exogenously placed in the root, give rise to definitely exogenous buds. If clear cases of pericyclic phellogen are confused with these, the interpretation of the phenomena of bud sports arising on roots will be delayed and much unnecessary confusion created in a problem that is already sufficiently complicated.

The appearance of buds in a pericyclic phellogen is by no means a very common occurrence. Several cases have been referred to and a few others might be cited; to these must be added the similar cases in which buds arise from the meristem layer lying internal to a "polyderm." This tissue (*97*, *114*) is in general much like periderm, but easily distinguished from it by the fact that all layers of cells do not give the characteristic suberin reaction with Sudan III. Although the cells of this tissue are arranged in radial series, not all the rings of cells are suberized. They seem to be formed by a succession of jerks of meristematic activity; the cells lying just within the innermost suberized layer start into activity and cut off radial series consisting of one or more cells, of which an outer cell becomes suberized while the innermost one remains alive and later resumes meristematic activity. Such an innermost cell, with its meristematic potentialities, is closely associated with the organization of the bud initial in the root of *Rubus idaeus*. (Pl. 13, D, E.)

When bud initials thus arise in the phellogen or the meristematic layer of polyderm, they are usually found opposite the primary rays of the root. It seems likely that this position is determined less by the original meristematic potentialities of the root pericycle at this point, opposite the protoxylem, than by the increased supply of solutes available opposite a parenchymatous stelar tissue as compared with that available in front of the sheet of prosenchymatous phloem elements, among which fibers are frequently included.

Adventive Buds and Branching of the Root

By far the most common case of bud formation in the root and the one which is almost the invariable rule with uninjured roots, is the case in which the bud arises in connection with the emergence of a branch root. A brief consideration of the phenomena involved in the emergence of a branch root throws a great deal of light upon this fact.

The new root was described by Van Tieghem and Douliot (*172*) as digesting its way through the endodermis and cortex, but their evidence for the existence of this "secretory pocket" at the apex of the emerging root was very inconclusive; an alternative interpretation is that the root emerges by the crushing and disorganization of the cortical cells and tissues.

Although the statement that the young root secretes digestive enzymes and thus makes its way to the surface is still commonly repeated in the textbooks, almost all critical examination of the question has led to the contrary conclusion. Thus, Vonhöne in 1880 (*178*), reported that while both enzymatic secretions and mechanical pressure played a part in the process, mechanical causes were mainly responsible. Pfeffer (*107*) came to the conclusion that the outward thrust of the root was purely mechanical, as also did Peirce (*105*). Lenz (*87*) more recently examined the same problem very fully and came to the same conclusion. Evidence as to the effectiveness of internal secretions in this case needs very careful examination; in the light of wider knowledge of the effects of pressure upon parenchymatous tissues (*67*, *68*) it is realized that under compression the intercellular spaces in the cortex become filled with sap, and as a result cell division such as noted by Peirce might occur in front of the advancing tip.

One very strong argument against digestion as a method of emergence is the existence of the Casparian strip. Microscopic observation shows the endodermal layer stretched and compressed in front of the advancing tip. The digestion of the endodermis involves the production of an enzyme or hydrolyzing agent capable of breaking up the varnishlike substance impregnating the Casparian strip. This substance resists concentrated sulphuric acid and in the test tube is broken down only by prolonged boiling in strong alkali. No enzymes capable of digesting such a substance are known, and it seems certain that the Casparian strip must be broken through by mechanical means. However, once this resistant, impregnated region of the wall is ruptured, the pressure exerted would be ample to break through the other walls intervening between the root apex and the exterior. Undoubtedly, therefore, mechanical pressure is adequate to force the root apex to the surface if the endodermis is once broken. The assumption of a special secretory apparatus seems unnecessary, and the evidence for its existence is as yet quite inconclusive.

This point has been argued in some detail because the general conclusion is of rather startling significance. In the unbranched root the vascular sap necessary for any prolonged meristematic activity is strictly confined within the stele, but the emergence of a branch root means a forcible and quite possibly a sudden break in the continuity of the endodermis. Such a break may be accompanied by a leak of sap from the endodermis into the cortex in the neighborhood of the gap.

That such leaks actually do occur seems clearly indicated by the fact that the region on the parent root around the base of the branch is frequently characterized by active cell division and proliferation, resulting in calluslike outgrowths. As Devaux (*29*) showed, such a callus is frequently the seat of a certain amount of phellogen activity, and Beijerinck's observations (*11*) showed that when buds occur normally upon the root system they are nearly always found on this callus, and usually very intimately associated with the cork phellogen when such is present.

The figures in Beijerinck's paper (*11*) clearly illustrate the great diversity exhibited by these calluslike growths occurring around the base of branch roots. The subterranean position in which such callus grows and the difficulty in obtaining undamaged specimens have caused the very wide distribution of this morphological character upon the roots of the dicotyledon to be but little suspected. The development of these curious cushions of tissue around branch roots deserves far more extended investigation than it has yet received, and its discussion in relation to the present problem must necessarily be confined to a mere indication of certain of the more salient features in its relation to bud formation.

It is obvious that if this tissue receives a free supply of sap from the root stele, where sap is often contained under pressure, it may here flow out along the walls, displacing the air in the intercellular spaces, so that the supply of water and solutes ultimately reaches the external walls of the cushion and in some cases even leaks from them. Root excretions have been reported by different observers, although the evidence as to their occurrence is contradictory. Unfortunately, in such physiological inquiries there seems to be not a single reference to the morphology of the root system under observation. Clearly the possibility seems very great that such root excretions may synchronize with the rupture which occurs when the branch roots emerge. The supply of solutes thus brought to the surface of a rapidly proliferating calluslike tissue has also great significance from the standpoint of plant pathology. The special vulnerability of this particular point of the root system to the entry of pathogenic organisms seems obvious (*190*).

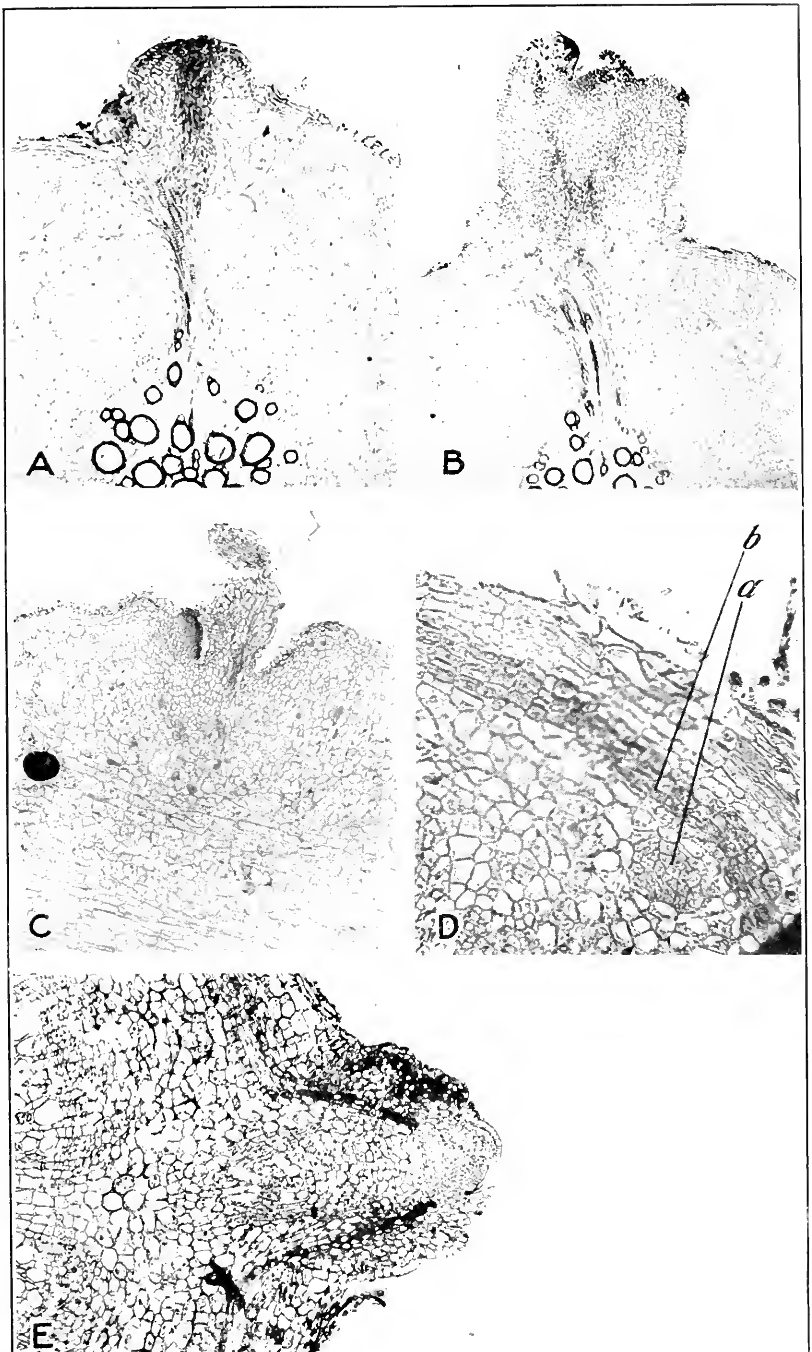
Sometimes this calluslike cushion develops as a protuberance above and below the base of the branch root; at other times it is more developed on the sides, while frequently it forms a ring around the emerging rootlet. The cushion may be small and barely visible to the naked eye, though usually it is clearly discernible when the root is cleaned free from soil; in some cases, like *Populus alba*, it grows into a corallike mass several centimeters in thickness, from which buds may apparently arise at any point. On the smaller cushions the buds may be quite regularly arranged. Sometimes a single bud is present at each branch, as in *Epilobium angustifolium*, where the bud at its emergence seems to be closely related to the meristem lying just within the polyderm. (Pl. 11, C.) In other cases, such as Linaria, several buds may be formed at the same time upon a single cushion, though only one is shown in Plate 11, D.

It has been seen that some significance attaches to the point of origin of the bud and that it is desirable to be clear as to whether its origin is endogenous or exogenous. With the development of buds upon the callus formed around the base of branch roots, this point may be very difficult to determine. There are here two separate problems to consider; the origin of the cushion itself and the point of origin of the bud upon this cushion. In most cases the first branch roots appear when the parent root is young and the primary cortex still healthy. As the branch root emerges, the tissues of the primary cortex around its base may be stimulated into meristematic activity, sometimes forming phellogen, sometimes bud initials. Thus in Linaria buds arise exogenously from the cortex but apparently only in association with the break in the endodermis produced by the emergence of lateral roots. So far as exogenous buds found upon the hypocotyl in this genus have been examined, the evidence seems to indicate that in the hypocotyl also the development of exogenous buds is closely connected with breaks in the endodermis and in some cases at least here also caused by the emergence of lateral roots.

Similarly, Plate 11, E and F (*Helenium autumnale* variety Riverton Gem) shows bud initials developing in the primary cortex of the old root, well outside the endodermis; these are formed only near the base of a branch root. In the larger bud (pl. 11, E) it will be noticed to what an extent the development of the shoot apex and leaf initials has proceeded without there being any indication of the procambial differentiation which will ultimately connect the buds with the stele of the root.

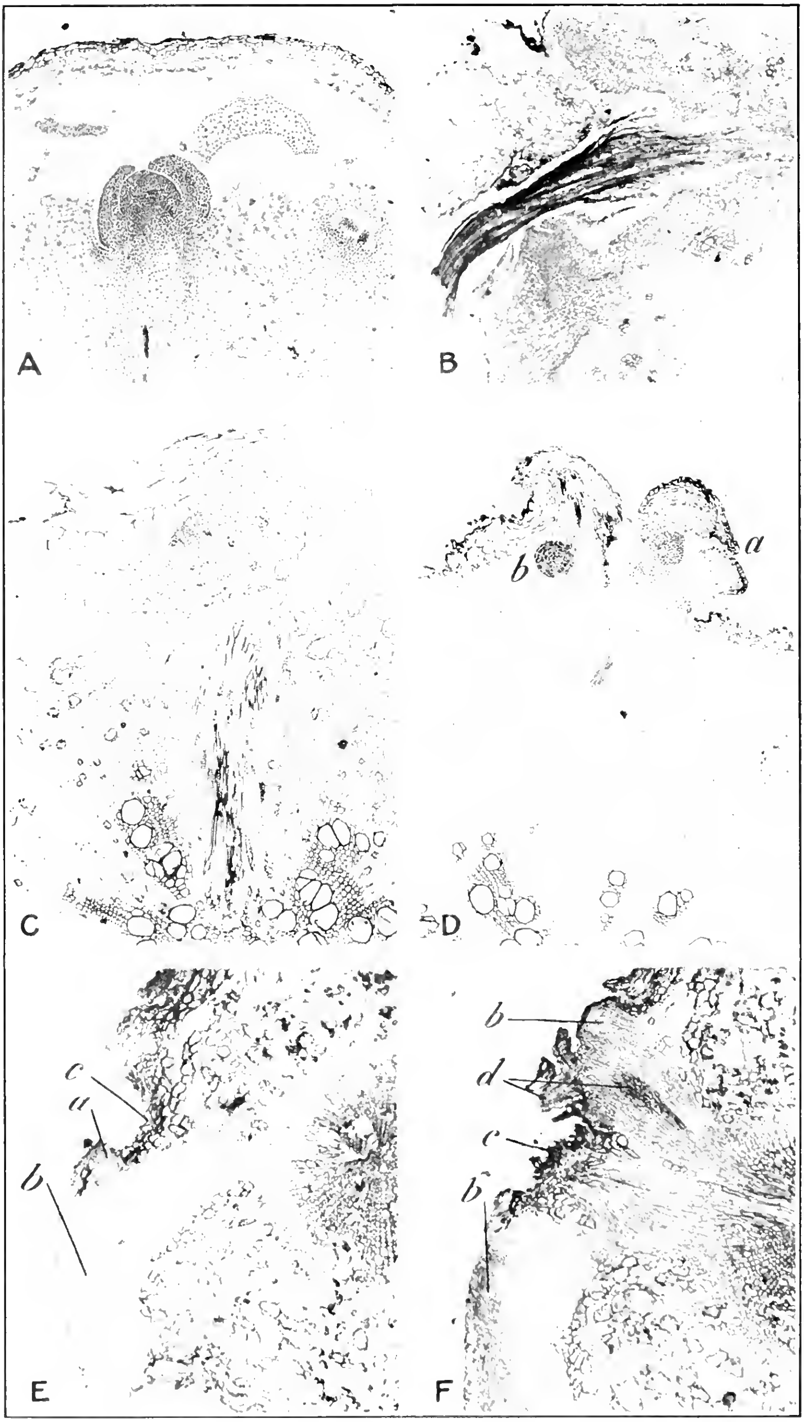
In many cases, however, either the branch roots appear later and traverse a shriveled cortex in which no response to leakage of sap from the stele is possible, or a pericyclic phellogen prevents the movement of materials outward into the primary superficial tissues. In such cases a vigorous cushion of tissue may still be formed around the base of the emerging rootlet, but it arises mainly if not entirely through the activity of the pericyclic phellogen.

The photographs of *Barbarea vulgaris*, *Isatis tinctoria* L., and the Princess variety of Pelargonium (pl. 13, A–C; pl. 14, E, F) illustrate cases of this type where the bud seems traceable to tissues which are closely associated with the pericyclic phellogen. In *Asclepias incarnata* the cork is exogenous (p. 52), but the buds form below the cork phellogen. (Pl. 14, A.) They are clustered around the branch root and appear to be endogenous, in contrast to the definitely exogenous examples furnished by Linaria and Helenium.



FORMATION OF ADVENTIVE SHOOTS ON ROOTS

A and B.—Root of *Barbarea vulgaris*, showing adventive buds arising in the pericyclic phellogen near the emergence of a branch root. A, × 90; B, × 65.
C.—Longitudinal section of root of *Isatis tinctoria*, a bud initial just to the left of the lateral root, closely connected with the pericyclic phellogen. × 45.
D and E.—Transverse sections of root of *Rubus idaeus*, showing stages in the origin of a bud (*a*) from the neighborhood of the meristematic layer within the polyderm (*b*). D, × 90; E, × 50



FORMATION OF ADVENTIVE SHOOTS ON ROOTS

(For explanatory legend see p. 49.)

These photographs of Pelargonium (pl. 14, E, F) also illustrate another anatomical complication. The bud-bearing callus tissue is here seen to form a somewhat wide and irregular mass around the base of the emerging rootlet. In Pelargonium, as in most dicotyledons, many of the rootlets emerging from a main root are temporary and die away at the close of the growing season, to be succeeded the following spring by a new crop of roots which emerge upon the main "scaffold" roots, usually appearing from the bases of the roots of the previous season; these arise either endogenously, as branches in the tissue of the root where it is still buried in the main axis, as in *Bocconia cordata* (pl. 22, A), or, less frequently, they emerge from the vascular cambium of the main stele in this region, as the new branch root appears to have done in the Pelargonium shown in Plate 14, F. These branch roots penetrate through the callus cushion, throwing the tissue in this region into still greater confusion, so that the exact source of the buds may be very difficult to trace.

Plate 14, B, shows a section of the root of *Thladiantha dubia* (♀ plant). This root exhibits a peculiar habit of growth, being dilated at intervals along its length. From these swollen portions no branch roots arise, though buds occasionally form, arising from the cork phellogen and, therefore, quite independently of branches; but in the narrow portion, the root branches freely, and buds are restricted to the regions around the bases of the branch roots. In the figure an old emergent branch root is seen, around the base of which the increase in girth of the mother root appears to have been retarded so that the branch emerges from a depression rather than from a cushion; but buds appear around the rim, and in section they seem to have a definite relation to the pericyclic cork phellogen.

Another mode of connection of the bud with the base of an emergent root is illustrated by Plate 14, C and D. These photographs of buds in different stages of development in Bocconia make it evident that these buds arise as outgrowths upon the flank of the emergent root and not in the tissues of the parent root. The buds are clearly endogenous in their relation to the parent root, arising well within the endodermis, probably within the pericyclic phellogen. It is impossible to define very clearly their position in relation to the tissues of the branch root, though they are probably endogenous here also.

EXPLANATORY LEGEND FOR PLATE 14

FORMATION OF ADVENTIVE SHOOTS ON ROOTS

A.—Root of *Asclepias incarnata*. Though the primary cortex is much broken up in the preparation, the buds can be seen to lie well below the exogenous phellogen. The larger bud is in close proximity with the vascular supply passing out to a branch root. ×35.

B.—Root of *Thladiantha dubia*. Just below the place of emergence of the branch root a bud initial has arisen in the neighborhood of the phellogen. ×30.

C and D.—Root of *Bocconia cordata*. C, A young bud initial arising upon the flank of a lateral branch root. ×45. D, A bud at the surface (*a*), closely connected with the old branch root, of which some traces are seen to the left of the bud. From the flank of the branch root a new initial can be seen at *b*, arising endogenously. ×35.

E and F.—Root of the Princess variety of Pelargonium: E shows a small bud initial (*a*) in the large meristematic cushion (*b*) near the point of emergence of a branch root (*c*). F shows how new branch roots (*d*) arise in this region after the old branch root has died off (*b*, meristematic cushion; *c*, old branch root). These new roots emerge through the meristematic cushion around the stump of the dead root. Both ×30.

In Phlox the callus is borne upon a region of the branch root which is already clear of the parent root. (Pl. 15, A.) The discussion of the casual factors contributing to the formation of the endodermis (p. 8) brought out that significance appeared to be attached to the diffusion of fatty substances from the wall of the stele and their contact with the air from the intercellular spaces of the cortex. In the case of an emerging rootlet there may well be a material difference in the extent to which air is present in the young cortex so long as this tissue is buried in the parent root; hence in this region and, after subsequent cell extension, for some distance out from the parent root, the endodermis of the branch root may not have developed under normal conditions. If under these changed conditions the diffusing unsaturated fatty materials have not met air as they leave the stelar tissue, they would continue to diffuse outwards. It is therefore very suggestive to find that in Phlox in this region of the branch root where the callus is borne the fatty substances have failed to form the usual continuous Casparian strip in the primary endodermis, but have formed instead irregular deposits through the cortex; these are deeply stained in the photographs. This feature has been noted only in the regions where the bud-bearing callus is present and in the region just behind this, where the branch is emerging from the parent root. Callus formation in this root is sometimes very extensive, and much cell division takes place within the main cortex, so that sometimes this may even be split open. (Pl. 15, B, C.)

Thus, especially in the case of normal root-borne buds, it is seen that in general a close relation exists between the presence of these buds and the existence of gaps or leaks in the endodermal cylinder where the branch root emerges, a gap which is usually characterized by the presence of a callus cushion. In some plants, although no buds appear upon this cushion normally, they may appear when the root system is isolated.

Root Branching Without Endodermal Leakage

There are a number of dicotyledon roots upon which no bud formation has ever been induced; and one reason for this may be the fact that in these roots the emergence of branches is not associated with any leakage in the endodermal system. Of course it must be remembered that negative evidence as to bud formation may always be upset, and the fact, for instance, that in the large family of the Crassulaceae no case of bud production from the root has ever been recorded may very well be due, as Beijerinck (*11*) pointed out, to the fact that vegetative propagation from portions of the shoot can so readily be carried out. Nevertheless, there is certainly good reason to associate the absence of buds in certain cases, and especially normally occurring buds, with the absence of leaks in the endodermis.

The branch root as it emerges from the parent axis and grows on as a normal root system invariably develops a primary endodermis with a normal Casparian strip in the layer of cells lying at the boundary between the stele and the cortex. This endodermis may arise so early in the development of the new root that a Casparian strip may actually develop upon a cell which at the same time or but very little earlier was developing a Casparian strip as a constituent of the endodermis of the parent axis. In this case the endodermis of the parent root makes a perfectly continuous connection with the primary endodermis of the young emerging branch, so that only a very temporary leak of sap from the stele into the cortex is likely to take place. The point of union is then a ring of cells which often appear to bear two bands of Casparian strip around their walls. In section such cells often show the characteristic outline of the Casparian strip in three places in the wall instead of two. Van Tieghem (*171, p. 705*) drew attention to this phenomenon, describing such cells as "triplissée."

Plate 15, D, shows a young branch root of Artemisia. The apex of the new root has not yet emerged from the tissues of the parent root, but already the endodermis has differentiated behind the meristematic apex and is seen to be in strict continuity with the endodermis of the main stele.

In other cases, although there is a lack of continuity between the endodermis of the main axis and that of the branch root, the temporary leakage at the base of the branch root seems to be stopped by the deposition of fatty substances in a continuous layer over the walls of the parenchymatous cells in the region of the gap. The various varieties of Pelargonium, commonly propagated vegetatively, have formed very erratic material as to propagation from root cuttings. The irregularity of the basal callus formed in the Princess variety has already been considered. The Monstrum variety has given uniformly negative results as regards propagation from root cuttings. Examination of the root of this variety in the neighborhood of a branch shows the endodermis of branch and axis to be joined by a group of irregular suberized cells. (Pl. 16, A.) The striking swellings shown on the radial walls of the cortical cells in the main axis in this section are not the Casparian strip but curious swollen rigid bars, impregnated with silica, which seem to be characteristic of the radial and transverse walls of the exodermis in Pelargonium (*173*).

Repeated attempts to obtain buds upon the roots of *Cheiranthus cheiri* proved entirely unsuccessful. In this plant the young root forms pericyclic cork at a very early age, and those of the main root and of the branch are continuous, and no signs of any swelling at the base of the branch root are shown. (Pl. 16, B.)

Callus and bud formation at the base of branch roots have now been traced to the presence of a break in the endodermis at this point, and the absence of the buds and callus in many cases is apparently due to endodermal continuity. There yet remain for consideration various other possibilities of leakage taking place through the endodermis.

Leakage Through the Old Endodermis with Consequent Formation of Exogenous Cork and Buds

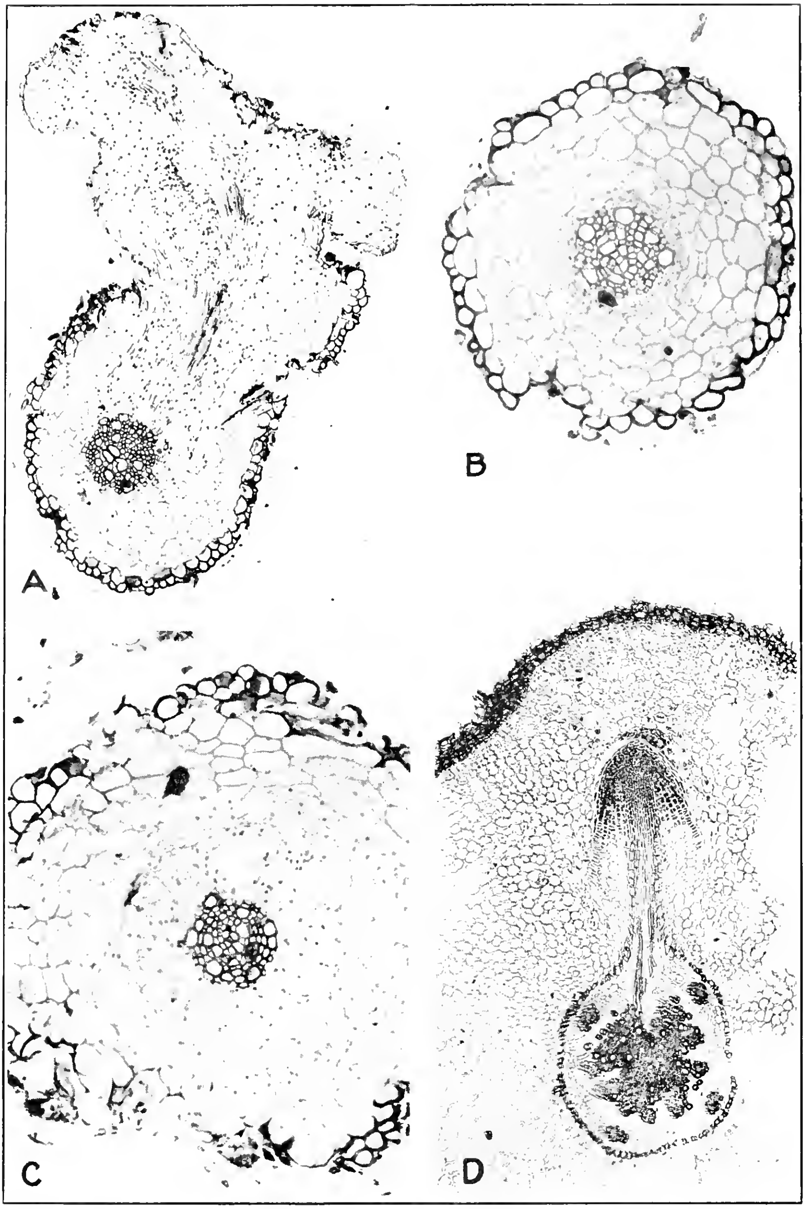
An endodermis does not necessarily remain an effective barrier against the outward movement of water and solutes. As has been seen, the retention of solutes and the osmotic control of water movement depend upon the semipermeability of the living protoplasts of the endodermal cells. This semipermeability is a function of the vitality of the cell, which usually becomes more permeable with age.

Thus, where the endodermis retains the primary structure throughout life, the older regions of the root may be subject to considerable leakage of solutes from the stele, and this is probably the explanation of the exogenous cork formation occurring in *Philodendron erubescens* C. Koch and *Monstera deliciosa* (*122*). In *Cichorium intybus* the cork forms exogenously outside the primary endodermis, but in this case it seems probable that leakage through the old endodermis is facilitated by the actual disruption of this layer which occurs with increase in girth of the stele. In many cases (pl. 16, C, D; pl. 17, B) the buds in this species occur well below the position of the exogenous phellogen, and in some cases at least they appear to initiate just within the endodermis, so that, though the cork is exogenous, the buds may be either endogenous or exogenous.

Usually the endodermal cells signalize their increase in permeability by the "creaming" of their fatty contents to the surface, where they form a continuous suberin lamella upon a base of cellulose. This is known as the secondary endodermal stage and is followed practically always in the angiosperm root by a tertiary stage in which an inner lamella of cellulose is deposited within the suberin lamella (*119*). After all cells of the endodermis have passed into the secondary or the tertiary stage, the endodermal layer becomes practically impermeable to both water and solutes; consequently this stage is usually followed by exfoliation of the primary cortex. But if passage cells are left—that is, cells which remain in the primary stage—the protoplasts of these cells may for a time allow solutes and water to move in either direction through them until, as a result of successive alternations of sap movement and drying of the tissues, the passage cells also become choked with the débris left by the ebb and flow. Until this happens such a tertiary endodermis may be associated with a living primary cortex in which exogenous cork and buds may appear, as in *Aristolochia clematitis* L. (Pl. 17, A.)

A wide range of different types, as regards the nature of the endodermal barrier and the position of the phellogen, is met with in the Solanaceae. In Lycium and Nicotiana, pericyclic cork was found to form very early in young, thin roots. In older roots of Lycium, buds were found emerging from this pericyclic phellogen, in association with the place of emergence of branches. In Nicotiana, buds were obtained only by cutting off the stem and inverting the root system, keeping the older region of the root in moist air. Buds then appeared in association with the phellogen, arising upon the older parts of the root system, at the base of branch roots. With *Cestrum newelli* Nich. and *Datura suaveolens*, in roots up to about 1 centimeter in diameter, the endodermis was found to remain primary, but probably was relatively permeable, as an exogenous phellogen was active outside it. In Capsicum and Physalis many cells of the endodermis had passed into the secondary, impermeable stage, but the presence of a number of passage cells explained the presence of exogenous cork.

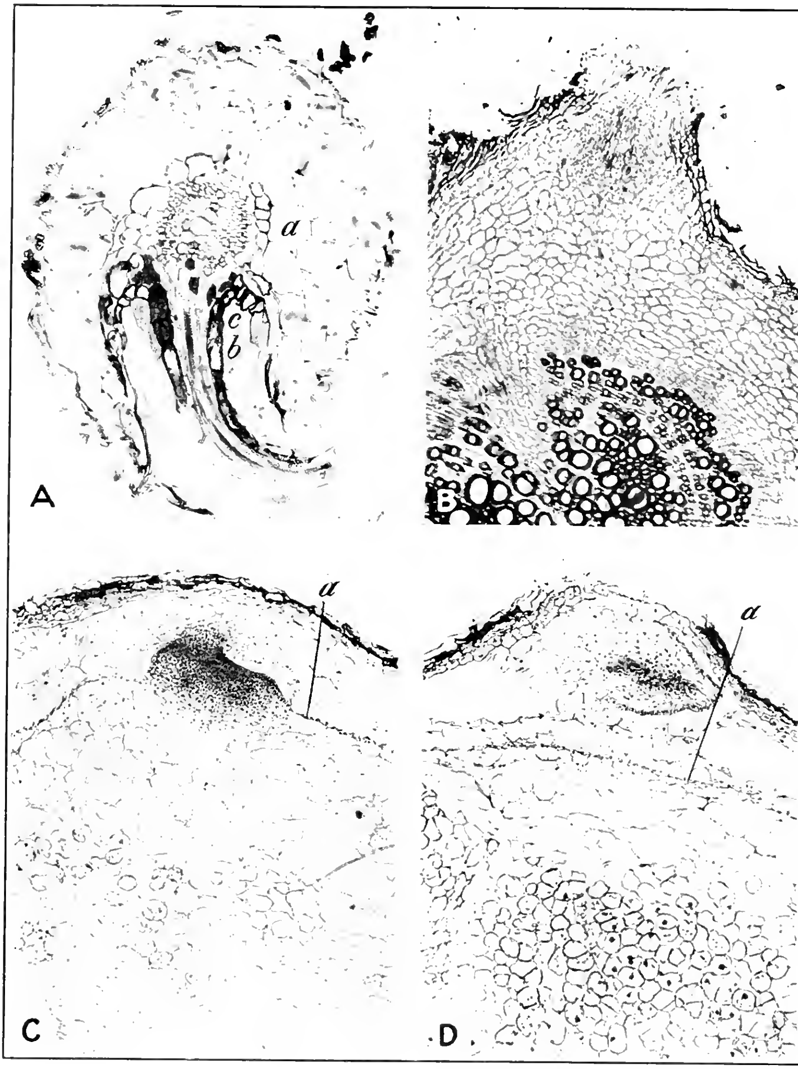
In *Solanum capsicastrum*, *S. crispum* Rz. and P., *S. dulcamara*, and *S. nigrum*, the increase in girth of the main roots, through cambial activity, takes place very rapidly. The endodermis is thus stretched until the cells are greatly extended in a tangential direction. Since they are no longer meristematic, and hence no increase



ROOT BRANCHING WITH AND WITHOUT ENDODERMAL LEAKS

A–C.—Root of Phlox, showing the manner in which the branch root dilates at its base as it emerges from the parent root. A, Branch root in longitudinal section at point of emergence, showing swollen hypertrophied cushion on which adventive buds are borne. × 50. B, Normal appearance of branch root as seen in transverse section. The primary endodermis, not visible in the photograph, is continuous. × 75. C, Same root close to the place of its emergence from the parent root. Cell division and extension have taken place in both stele and cortex, and the primary endodermis is much interrupted in this region. × 85.

D.—Transverse hand section of the root of Artemisia, showing an early stage in the emergence of the branch root. The endodermis of the parent root is clearly continuous with the endodermis of the branch root. × 40.

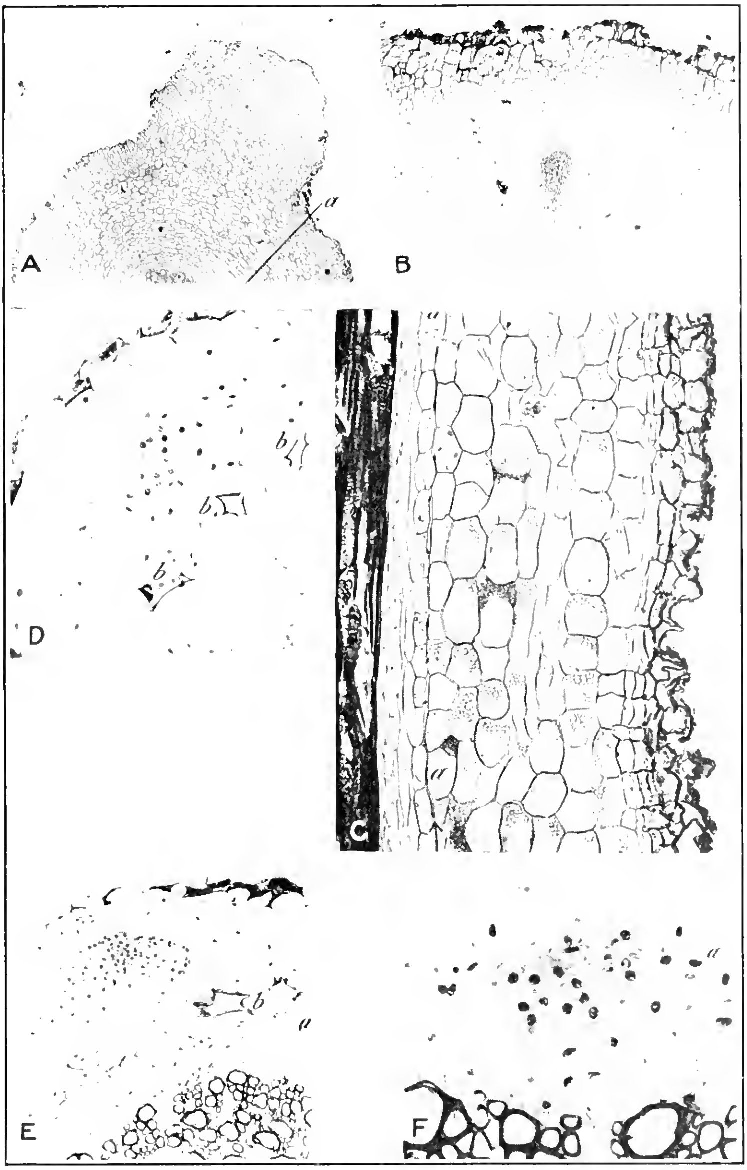


ENDODERMAL STRUCTURE AND ADVENTIVE-SHOOT PRODUCTION

A.—Section of root of the Monstrum variety of Pelargonium, passing radially through the emerging branch root. Between the endodermis of the main root (*a*) and the endodermis of the branch (*b*) lies a group of cells (*c*) with fat-impregnated walls. × 135.

B.—Root of *Cheiranthus cheiri* at the point of emergence of a branch root. The cork of the parent root is continuous with that of the branch root. × 100.

C and D.—Transverse sections of the fleshy root of *Cichorium intybus*. The endodermis (*a*) is primary and evidently permeable, for the exogenous phellogen is active outside it. In C the bud is well below the phellogen and probably arose within the endodermis. In D another bud is shown which lies just beneath the phellogen and undoubtedly is completely outside the endodermis. Both × 65.



ENDODERMAL STRUCTURE AND ADVENTIVE-SHOOT PRODUCTION

A.—Transverse section of root of *Aristolochia clematitis*, showing a bud arising just beneath the exogenous phellogen. The position of the endodermis is indicated at *a*. × 25.
B.—Longitudinal section from the proximal end of an isolated root piece of *Cichorium intybus*, showing the formation of a new shoot initial some distance below the cork phellogen. × 30.
C.—Longitudinal section of root of *Solanum capsicastrum*. The exogenous cork is visible on the right. Between this and the stele, at *a*, *a*, traces of the collapsed primary endodermis are visible. × 75.
D–F.—Bud initials in transverse sections of Gaillardia roots. D and E show leakage through the primary endodermis (*a*), indicated by the heavily stained secretions (*b*) in the intercellular spaces just outside the endodermis. These leakages are associated with the exogenous buds. D, × 100; E, × 55. In F no development of a secretory system is shown outside the primary endodermis (*a*), and meristematic activity is visible just within the endodermis. × 140.

FORMATION OF ADVENTIVE SHOOTS ON ROOTS

A. Root of *Cnicus arvensis*, showing an exogenous bud obtained after isolation of the root system; *a*, the endodermis. × 50.
B. Root of *Fuchsia caledonia*, showing a mass of callus which has formed beneath the polyderm at the base of a branch root and which bears several young shoot initials. × 10.
C. Root of *Romneya coulteri*, showing a bud obtained after isolation. Although opposite a primary xylem group, it showed no connection with the emergence of a branch root. × 35.
D. Longitudinal section through an isolated root piece of *Filipendula ulmaria*, showing a callus, bearing a bud initial at *b*, arising from the activity of the tissues of the stele, within the secondary endodermis (*a*). The cells at the cut surface of the primary cortex merely suberized and took no part in callus formation. × 25.

in their numbers is possible, with the increasing tension this layer is ruptured. At the time this happens the primary cortex is still present on the root. After the rupture it is very difficult among the crowded parenchymatous tissue to find traces of the crushed and disorganized endodermis, but it is possible to trace the process and see how this disruption occurs. (Pl. 17, C.) On occasional roots of *S. nigrum*, an endogenous pericylic phellogen is present, formed before the endodermis is disorganized. Usually, immediately after the rupture, vigorous meristematic acivity sets in near the surface of the root and a cork-producing exogenous phellogen arises. In close connection with this phellogen, buds are often found. Beijerinck (*11*) called particular attention to the vigorous capacity for vegetative propagation displayed by the roots of *Solanum dulcamara*, which he described as being in many cases covered with buds.

The same disorganization of the secondary endodermis, taking place before the primary cortex disappears as the result of the increase in girth of the stele, is seen in *Asclepias incarnata*. In this plant, however, the exogenous cork is visible in very thin roots when the secondary endodermis still seems to be practically continuous, while in the thick, older roots all traces of this endodermis are usually lost. Buds occur normally upon the roots; they apparently commence to form several cell layers below the active phellogen and not necessarily in connection with branch roots. (Pl. 14, A.) From the anatomical conditions existing at the time of their formation, it is very difficult to decide whether or not these roots are endogenous in the sense of arising from the original horizon of the pericycle.

In the Compositae, events seem to follow a course slightly different from that just considered. As Tetley pointed out (*164*) in this family the stele seems to release unusual quantities of fats and fat-soluble substances, especially from the phloem. The result is that these substances dissolve in the Casparian strip and pass through it, collecting in the intercellular spaces of the cortex just outside the endodermis. They appear first in the regions opposite the primary phloem in the young root, but as secondary growth proceeds they continue to be released, so that in time the intercellular spaces all around the main part of the cortex may become impregnated with this material, which vigorously reduces osmic acid and readily takes up Sudan III and other fat stains.

The presence of this intercellular secretory system, characteristic of many of the Compositae, seems to stimulate considerable meristematic activity in the cortex. The first evidence of this is the appearance of groups of densely meristematic cells bordering upon the intercellular spaces. These groups of cells are usually described as epithema, but in their course of development they follow the secretion and are probably caused by its presence, instead of being the active agents in secretion, as has usually been assumed. Exactly the same sequence of events has recently been described by Hanes (*51*) for the epithema clothing the resin canals of the conifer.

But, as Plate 17, D and E, shows for Gaillardia, the leakage of these fatty substances through the endodermis may also be associated with exogenous bud initiation. These buds were found to occur only in places where the intercellular secretions were accumulating, and, as is shown in Plate 17, F, where these secretions were not yet present outside the endodermis, evidence was obtained for the existence of endogenous meristematic activity; thus in Gaillardia, it seems that buds might be either endogenous or exogenous in origin. From the material examined at Leeds, they appear to be usually exogenous.

Effect of Isolation upon Bud Initiation

In the account so far presented of the development of adventive buds upon the root system all buds have been treated in the category of "adventive," whether occurring as a normal thing upon the growing root system or formed only as the result of isolating a part of the root in an attempt at propagation. *Teucrium scorodonia crispum* (Stansfield) Rayner may be cited as an example of the latter case. In spite of repeated attempts, buds had never been successfully obtained upon this variety of the wood sage until the entire root system was isolated, the stump of the plant inverted in the soil, and with the ends of the root buried, the proximal portions of the root system exposed in very moist air. Buds then arose from the bases of the branch roots, and the leaves upon the shoots retained the crisped character of the original strain. Buds around the bases of branch roots were also obtained in *Clerodendron trichotomum* and *Geranium sanguineum* only after pieces of root had been cut off and left partially buried in a moist, porous soil. The same was true for *Cnicus arvensis* Hoffm., except that in this case the buds arose exogenously, upon the main root. (Pl. 18, A.)

With plants of *Fuchsia caledonia* Hort. in which the entire stem had been removed, but in which the root system was left undisturbed in the soil, a few buds were obtained from the cushions occurring at the base of the branch roots. As Plate 18, B. shows, such buds arose from the meristem layer, lying just within the polyderm. Plants of *Romneya coulteri*, similarly decapitated, produced buds from the neighborhood of the pericyclic phellogen which showed no connection with the branch roots. (Pl. 18, C.)

Where lateral buds are thus obtained upon the root surface as the result of isolation, it is of course always possible that more extended observation might reveal the buds occurring upon plants that were intact, growing under certain environmental conditions. There are, however, a very large number of cases where the buds produced after isolation arise from the surface of the callus, which gradually covers the wound. In such cases the root may also bear buds normally in a lateral position, as occurs in *Crambe maritima*, *Cichorium intybus*, *Verbascum nigrum*, and others, or it may be that the only root-borne buds known for such plants are "wound buds," of which *Primula denticulata* and *Morisia hypogaea* Gay. may be mentioned as examples investigated at Leeds.

CALLUS BUDS

Cases of adventive buds arising from the wound callus are not entirely limited to fleshy roots, one example (Crambe) of which has been discussed rather fully, although they arise much more commonly in such roots. This fact is apparently closely correlated with the larger reserves of food and water which such roots contain. Naturally, if functioning roots are present upon the isolated root segment, or can be developed from existing branches, the water supply will be much more certain, and this is probably in part the reason for the success obtained with Teucrium and Fuchsia. Sometimes, again chiefly with fleshy roots, young roots may be regenerated from the wound surface, but, as has been discussed, such new root initials usually appear comparatively slowly and long after the proximal callus is covered with bud initials.

Primula denticulata, *Filipendula ulmaria*, and *Ajuga reptans* (pl. 18, D, and pl. 19, A) furnish examples of callus buds which are formed in relatively slender roots containing a secondary or tertiary endodermis. As was pointed out above, the endodermis restricts the flow of sap to the cortical regions, and, although the primary cortex was still present in the mother roots in these cases, it will be seen that this region has taken no part whatever in the production of the bud-bearing callus. *Plantago lanceolata* L. also shows buds on the callus of a thin root; buds were also found around the base of branch roots in this species. (Pl. 19, B.) Buds were found in the same position on the roots of *P. media* L., which Beijerinck (*11*) described as differing from *P. lanceolata* in its apparent inability to bud. Although in the isolated root of *Acanthus montanus*, illustrated in Plate 19, C, the endodermis was still probably in the primary stage, callus production was confined almost entirely to the cambium region, though a cork phellogen has formed beneath the suberized cells at the cut surface of the pith and cortex.

In Plate 20, B (*Solanum capsicastrum*), a marked phellogen is shown in the cortex. As already described on page 52, the secondary or tertiary endodermis in this root is disrupted and scattered by the increase in girth which the stele within undergoes at a very early stage. In fact here, as in most of the relatively fleshy roots that are to be considered in this connection, any distinction between cortex and stele can be disregarded. If the endodermis is still present in such roots it is usually leaky or disorganized, as in the case of many Compositae and Solanaceae; in other cases the primary cortex has long since disappeared as the result of the formation of pericyclic cork as in *Crambe maritima;* when this occurs, the secondary phloem is either so parenchymatous or such continued division of the parenchymatous pericycle cells originally present has taken place that the outer portion of the root, though within the original pericycle, is as parenchymatous as typical cortex.

FLESHY ROOTS

The typical fleshy root is thus one in which the activity of the vascular cambium has produced a disproportionately large amount of parenchyma, although there may be a core of lignified elements near the center. Both this parenchyma and the residual primary parenchyma lying between xylem and phloem or making up the pericycle display considerable activity in growth. In the fleshy roots of many of the Umbelliferae the secondary tissue is exceedingly irregular, rings of xylem and phloem surrounding isolated groups of primary xylem which have been broken up and scattered by the enlargement and multiplication of the parenchyma cells originally present among the vessels.

In Beta, most of the root is produced by the activity of a succession of concentric rings of cambium which commence their activity afresh farther and farther toward the periphery of the root. The parenchyma between the successive rings of vascular tissue, however, remains active in division and practically keeps pace in its increase in girth with that occurring in the neighboring rings of parenchymatous vascular tissue.

Where tissues behave so anomalously as these, it would be unwise to press any generalization based upon the usual sharp categories of vascular differentiation. In other roots correlations have been made between the places of emergence of adventive structures and the relative position of xylem and phloem, but it is doubtful whether such correlations can be applied to many of these fleshy roots in which the original organization of the primary tissues is sometimes completely masked and in which the behavior of the secondary tissues is so anomalous. The main general characteristic of the fleshy root is the presence of a large amount of parenchyma which shows a considerable tendency to divide. This may very well be correlated with the high water content of these fleshy tissues, and with the fact that the intercellular spaces are small and are often filled with sap rather than air.

In England the propagation of the hop (*Humulus lupulus*) is accomplished by earthing up in summer the bases of the twining stems or even by laying the spirally coiled stems along the ground, partly buried in soil so that half of each spiral turn is in the ground. The portions of the stem thus earthed up remain vigorous and turgid, while the rest of the bine dries and ceases to grow. The earthed-up portions not only remain alive, but they swell up and undergo considerable permanent increase in girth. Anatomical examination shows that vigorous growth and division of the xylem parenchyma have occurred and scattered the dead lignified elements. The cambium also remains alive and vigorous, and the ray cells extend radially, and the cortical tissues also remain vigorous.

These swollen portions of the bine can then be used for the propagation of the plant in the spring, when vigorous endogenous root production takes place from the neighborhood of the cambium and the surface of the swollen shoot becomes covered with adventive buds. In the spiral layers the portions of the stem which have been exposed to the air all winter are dry and dead. The striking difference shown by the alternate portions seems mainly to be due to the water content of the tissues; in the one case the high water content has not only maintained the cambium in a vigorous condition but has also promoted a very widespread cell division throughout the parenchymatous tissues, followed by the vigorous production of exogenous adventive shoots. Anatomical details of this method of propagation of the hop merit further examination. These few facts suffice to call attention to this case as an example of the marked effect upon the cell growth and the production of adventive structures, resulting from the maintenance of turgidity in living parenchymatous tissue. Just these conditions prevail in the fleshy roots under consideration, and they probably have much to do with the vigorous activity in vegetative propagation which such roots commonly show.

On page 31 adventive-bud formation from the callus was described for the shoot, and many of the facts there brought out apply equally to the buds which arise from root callus. Such adventive-bud production is not very common upon the shoot, and, as Beijerinck (*11*) pointed out, in the case of decapitated trees the nearer the cut is to the base of the trunk the greater the bud production. From this standpoint the much greater bud production displayed by the root than by the shoot in such a plant as Crambe is perhaps intelligible, the tissues containing more sap toward the base of the plant.

But by no means can buds be obtained from the callus in all fleshy roots. The necessary healing of the cut surface in such a parenchymatous tissue depends upon suberization, and the meristem forms later. Cocks [9] found that isolated roots of hyacinth, narcissus, and other monocotyledons suberized very slowly and at irregular depths below the cut surface; "etagen" cork later arose beneath the suberin block, but frequently decay set in before this process of healing was completed.

Formation of wound callus and phellogen among the monocotyledons seems almost entirely restricted to the Liliaceae, Dioscoreaceae, and Orchidaceae. Although Beijerinck's (*11*) account of bud formation on these roots suggests that further observations are needed, occasional instances of bud formation upon isolated root systems among these three families seem to have been observed.

Likewise in the dicotyledons the healing of isolated root systems is by no means always accomplished. It must be remembered that at the cut surface the primary cortex, if present, is often isolated from the stele, and as a result it frequently suberizes slowly and inefficiently and provides a surface from which decay may spread. Furthermore, within the endodermis the tissues may be mainly vascular and incapable of the wound response characteristic of parenchymatous tissues. As their liquid contents are displaced by air, the xylem tracheae, especially in woody roots, sometimes become filled with tyloses from the neighboring parenchyma cells (*75*) (pl. 20, A), and a phellogen may thus be enabled to spread across the cut surface; but frequently such roots decay before any signs of adventive buds have appeared.

In the more parenchymatous roots there is great variation in the rate and extent of suberization and phellogen formation displayed. Bebbington [10] examined the healing taking place in slices of red and sugar beets and parsnip; he found that in these plants the wound phellogen was slow in forming. In Beta he found that a very thin suberin film had formed over the cells near the cut surface by the end of two weeks, but even after three months the phellogen, which first appeared above the outermost ring of cambium, had not yet reached the interior of the root. On the other hand, in the root of *Erodium macradenum* L. (pl. 20, D), in which a very vigorous cork formation occurs in the pericycle as a normal thing, both proximal callus and distal callus were cut off by a very vigorous periderm.

This correlation between a vigorous normal phellogen and a vigorous wound phellogen is probably more than a mere coincidence.

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[9] Cocks, A. M. THE GROWTH HABIT OF THE MONOCOTYLEDONOUS ROOT SYSTEM. Leeds. 1925. [Unpublished thesis.]

[10] Bebbington, A. G. WOUND HEALING IN STORAGE ROOTS. Leeds. 1926. [Unpublished thesis.]

Pastinaca sativa and *Daucus carota* are examples of roots in which normal pericyclic periderm found at the surface of the swollen root is often slight or even absent, the surface being in the latter case protected simply by the remains of a suberized endodermis or by an irregular suberization upon the superficial cells. Bebbington[11] investigated the results as regards wound healing obtained with slices of two individual roots of Daucus, one root possessing a normal periderm and the other not. At the cut surfaces of slices subjected to comparable external conditions the root with the periderm formed a wound phellogen and the root without normal phellogen did not.

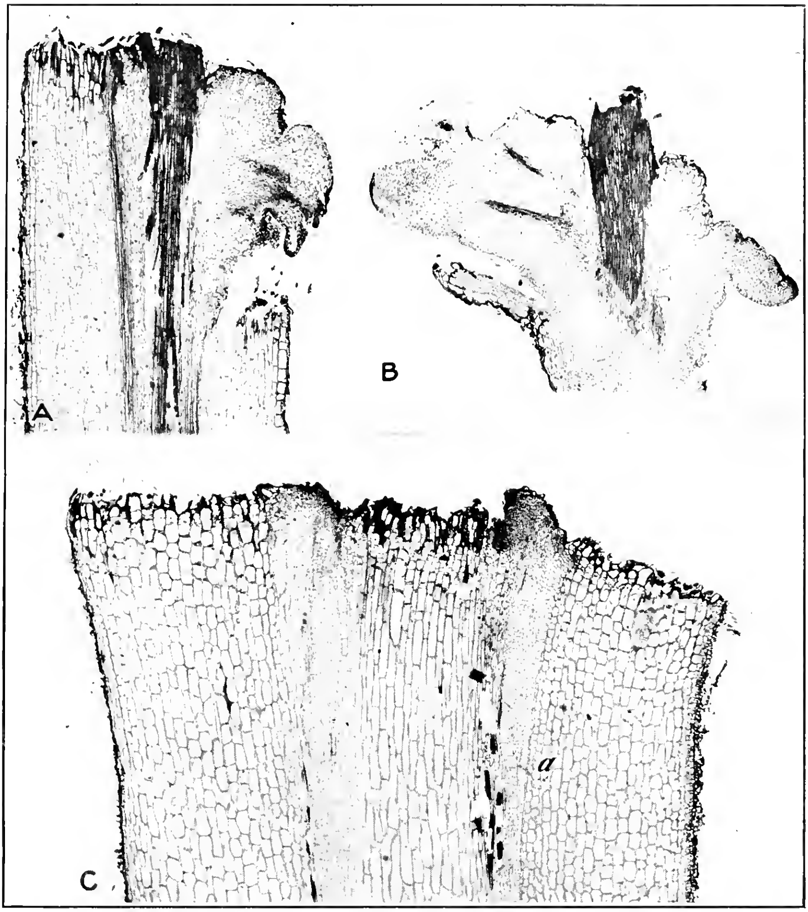
Whether the periderm is but slightly developed, as in Pastinaca and Daucus, or is present as an extensive and complete layer, as in Erodium, the amount of phellogen activity is always greater at the distal (root) end of long pieces of root, however the cutting is placed in regard to gravity. In roots as in stems frequently a definite phellogen activity can be traced at the lower (in this case the distal) end, but not at the proximal end. This has been seen in *Eryngium alpinum*, *Radicula armoracia*, and *Taraxacum officinale*. (Pl. 20, C.)

Even though there may be no distinct phellogen layer found at the proximal end, patches of callus cells near the surface may become meristematic and organize themselves as shoot meristems. Indications of adventive buds forming at the proximal end of the root are shown in Plate 20, C; similarly they have been seen in *Anchusa italica* (pl. 21, A) and *Symphytum officinale* var. *argenteum* at the proximal end (pl. 21, B) and at both cut surfaces of *Centaurea montana* and *C. babylonica* (pl. 21, C), in all these cases there being no indication of any previous phellogen formation in the callus. When phellogen is present, as a rule the relation of the buds to it seems to be essentially as described for *Crambe maritima*. In *Cichorium intybus*, however, although the adventive shoots occasionally begin closely associated with the phellogen, they usually appear some cells below. (Pl. 17, B.) It was pointed out previously that although normal cork formation is exogenous in this plant, lateral buds sometimes appear to be endogenous. A still further peculiarity exhibited by this species is referred to under "Adventure embryos" (p. 78).

It is thus seen that the connection between phellogen and adventive-bud formation is by no means obligate in either root-borne or shoot-borne callus. In the case of very vigorous periderm formation, as in Erodium, there may be very few buds produced, and conversely vigorous bud formation may occur from a callus in which no phellogen can be recognized. The generalization that still seems to hold is that a tissue organization which is favorable for phellogen activity is also favorable for the formation of adventive shoots. In the case of seakale, a third type of meristematic activity was also seen to occur at the distal end; beneath the phellogen a meristem formed, which is intimately associated with the vascular cambium and which also cuts off toward the inside elements that are quickly lignified. The presence of this layer seems to be associated with root formation from the wound tissue at this end.

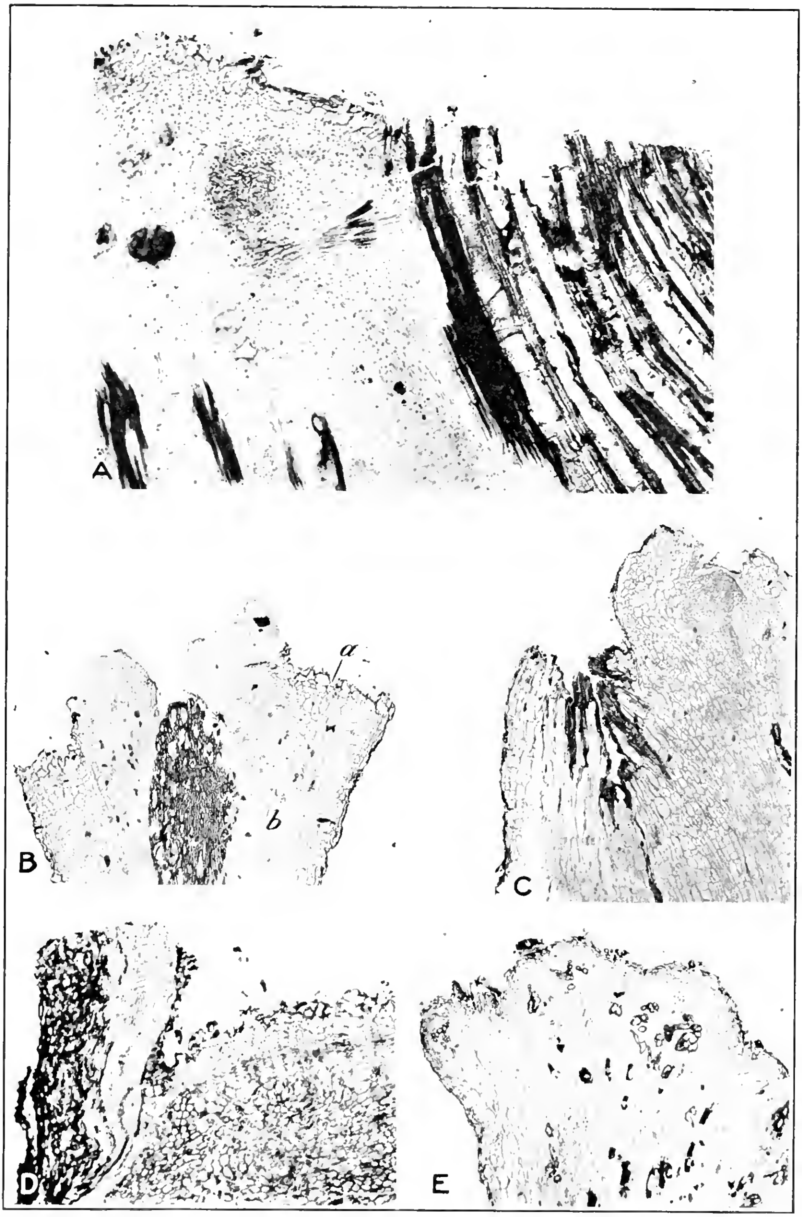
Indications of the presence of similar layers, though not necessarily having any connection with root formation, have also been

[11] See footnote 10 on p. 57.



ACTIVITY OF STELAR TISSUES IN FORMATION OF SHOOT-BEARING CALLUS

A.—Longitudinal section of root piece of *Ajuga reptans*. On the left the cells of the primary cortex have merely suberized. All callus growth and meristematic activity have developed from the tissues of the stele, and the callus bearing the bud on the right side of the section has no direct genetic connection with the primary cortex beneath it. × 35.
B.—Buds developing freely upon the callus arising from the stelar tissues at the end of an isolated root piece of *Plantago lanceolata*. The section is obliquely longitudinal and runs through the cortex of the root below and the protruding end of the central core of the xylem above. The xylem near the cut surface is discolored and disorganized. × 25.
C.—Longitudinal section of an isolated fleshy root of *Acanthus montanus*. The endodermis (*a*) is primary, and although callus formation and buds are found mainly over the region of the vascular cambium, a cork phellogen can be traced entirely across the tissues of the primary cortex. × 15.



MERISTEMATIC ACTIVITY IN ISOLATED ROOTS (LONGITUDINAL SECTIONS)

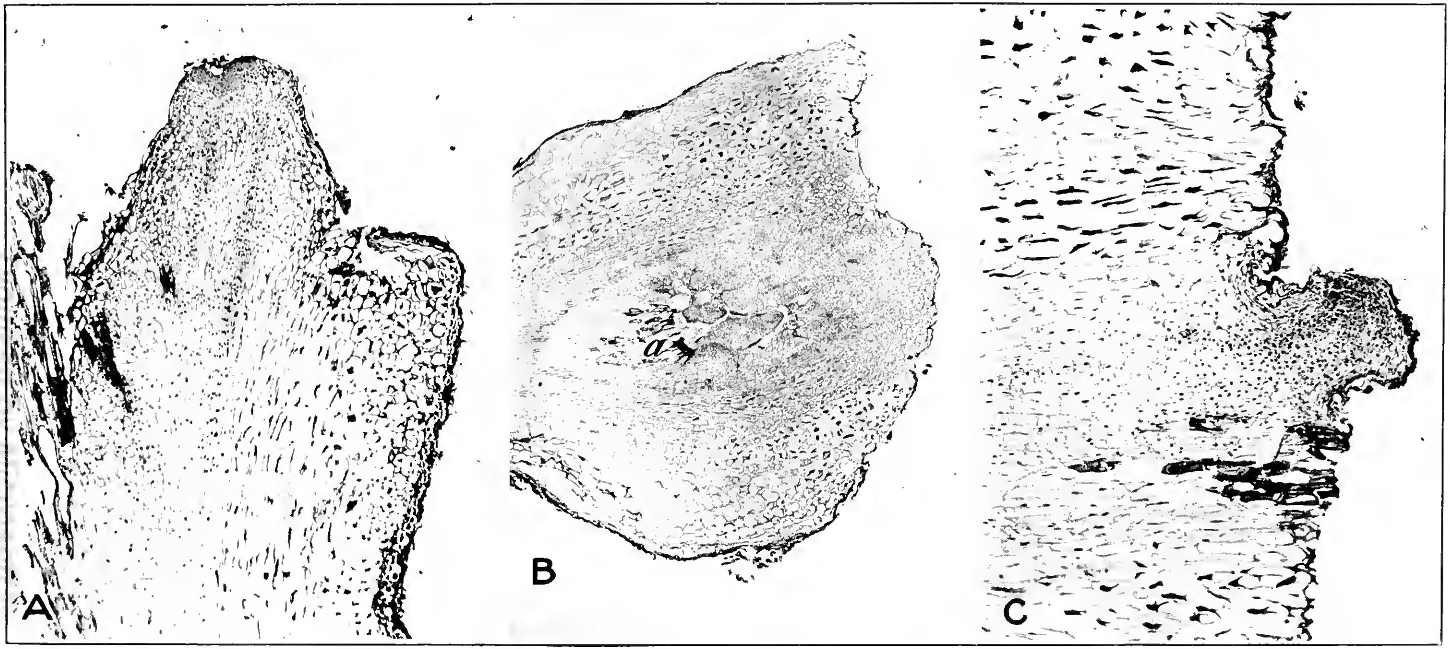
A.—Isolated root of *Sphaeralcea pedata* Torr., showing a bud-bearing callus over the region of the cambium and tyloses in the old xylem vessels. × 60.

B.—End of a budding root piece of *Solanum capsicastrum*. Although the callus with buds arises from the cut surface of the stele, an active phellogen (*a*) is formed below the suberized cells near the cut surface of the cortex. The endodermis (*b*) is collapsed and broken, and an exogenous cork is present at the cut surface of the root (see pl. 17, C). × 25.

C.—Proximal end of an isolated root piece of *Taraxacum officinale*. No cork phellogen is visible at the cut surface, but over the region of the cambium a shoot initial is developing. × 35.

D.—Distal end of a root piece of *Erodium macradenum*. The cork upon the normal root surface (at the left) has many layers, and the phellogen formed beneath the cut surface has also been very active. × 40.

E.—Characteristic type of callus formed at the distal end of an isolated root of *Silene nutans*. Some distance below the cut surface an active meristem is cutting off short xylem tracheids to the inside. × 25.

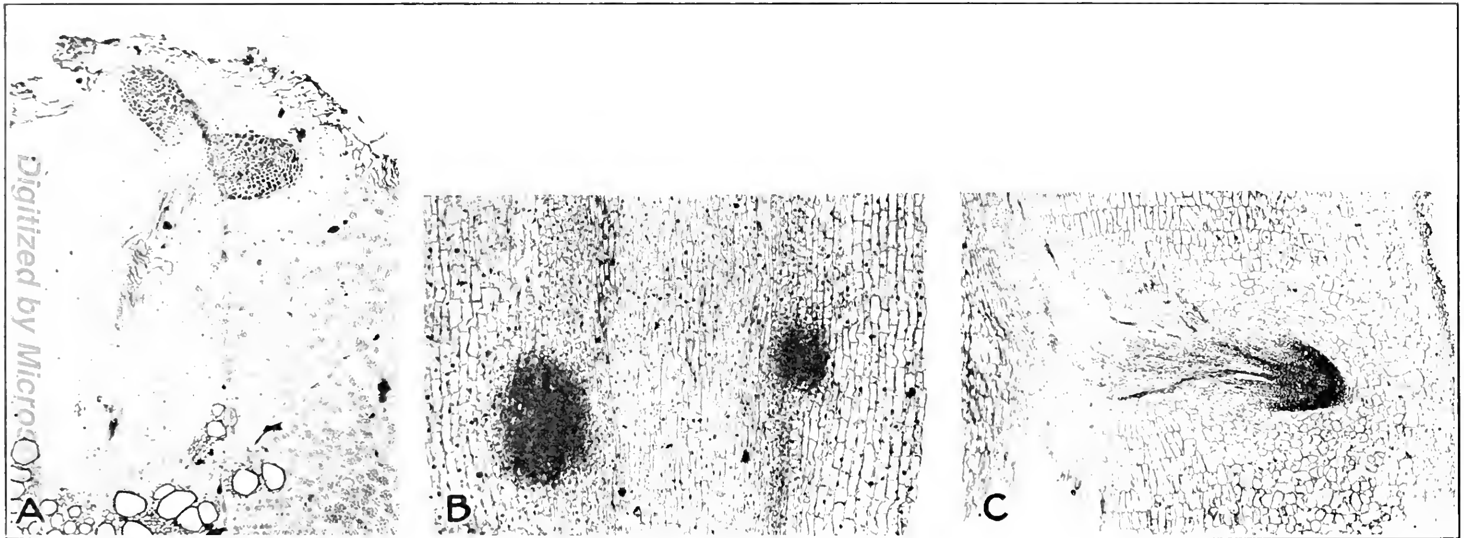


ACTIVITY OF STELAR TISSUES IN FORMATION OF SHOOT-BEARING CALLUS

A.—Longitudinal section through the proximal end of an isolated root piece of *Anchusa italica*, variety Dropmore. The bud initial arising at the cut surface of the callus developed above the cambial region has been preceded by many active cell divisions with periclinal walls, but there is no clearly organized phellogen. The backward differentiation of the procambial strands of the new buds is clearly indicated. × 15.

B.—Oblique longitudinal section of the proximal end of an isolated root piece of *Symphytum officinale* var. *argenteum*. At *a* are the deeply stained ends of the xylem elements originally exposed at the surface of the cut. These elements are nearly buried beneath the enveloping callus which has grown up over them from the cambial region. Buds are now forming on the inner side of the fused mass of callus. × 15.

C.—Bud-bearing callus at the exposed proximal end of a root piece of *Centaurea montana*. Suberin, but no phellogen, is visible at the cut surface. × 15.



ROOTS ARISING ON ROOTS

A.—Transverse section of a root of *Bocconia cordata*. Part of the emerging vascular strand of an old branch root is visible, and from this two new branch roots are arising endogenously. × 15.

B.—Longitudinal section of a young radicle of Cucurbita. A lateral root initial is present in the pericycle on either side of the stele in which the vascular elements are as yet but slightly differentiated. × 15.

C.—Longitudinal section of an isolated root piece of *Cichorium intybus* in which a new branch root is arising from the neighborhood of the vascular cambium. × 30.

observed in *Eryngium alpinum* and *Taraxacum officinale*, as well as in the parsnip and beet (Bebbington).[12] In *Silene nutans* L., *Scabiosa columbaria* L., the Souvenir de Bonn Abutilon, *Solidago recurvata* Willd., and the Belladonna Delphinium the only meristem found in the callus was of this type, indications of phellogen activity being slight or nonexistent; and it is perhaps significant that no buds were obtained from the cut surface of these roots, notwithstanding the vigorous callus formation. (Pl. 20, E.) In the parsnip, Bebbington [12] observed such an inner meristematic layer forming across the xylem beneath the cut surface, and Kupfer (*80*) found roots produced from the wound callus, but only in pieces of xylem from which cambium and phloem had been removed.

Other fleshy roots with which negative or but slightly positive results were obtained include *Althaea officinalis* (negative), *Hieracium maculatum* Schrank (negative, with well-marked wound cork in callus), *Maclura pomifera* (a bud on one specimen), and *Inula helenium* (negative). In *I. conyza* DC, buds arose at the proximal surface. Kupfer (*80*) also records negative results as regards bud production, for the fleshy roots of *Daucus carota*, *Brassica rapa*, *Raphanus sativus*, and *Tragopogon porrifolius*.

Crambe maritima behaved differently from most fleshy roots in the freedom with which it formed buds over the xylem region; probably the difference is to be correlated with the very parenchymatous nature of the xylem in this plant. In *Cichorium intybus*, callus was more pronounced above the rays than over the xylem; but in most roots the callus forms most markedly above the cambial region. Presumably the regions made up of parenchymatous or meristematic cells are the ones contributing the most to the formation of the callus. In the case of *Radicula armoracia*, although buds arise at the normal surface and from the callus, no buds were obtained from isolated portions containing xylem tissue alone in the Leeds laboratory, though Kupfer (*80*) succeeded in obtaining them from slices of xylem tissue alone. In *Pastinaca sativa* such isolated pieces of xylem tissue on one occasion gave rise to roots from the callus, the only occasion on which roots were obtained from the wound callus in the parsnip.

Evidently, the great diversity exhibited by bud production from roots precludes any absolute classification of types; nevertheless, it seems clear that certain anatomical features of the root are of marked importance in determining its behavior in vegetative propagation.

ADVENTIVE ROOTS

ROOTS UPON ROOTS

The same difficulty in giving precision to the term "adventive" exists in the case of the root apex as in that of the shoot apex. Even though branch roots usually arise in regular acropetal succession behind the growing apex, they do not necessarily begin in tissue which has remained meristematic since its separation from the apex of the parent root. As the result of injury, new root initials commonly arise, out of order, and from nonmeristematic tissue, but

[12] See footnote 10 on p. 57.

there is no very clearly defined order about the crops of secondary branch roots, which in many species arise regularly on the scaffold roots, replacing the crop of roots which had died down at the end of an earlier growing season.

Many roots arising upon roots, therefore, would fall under most definitions of "adventive," and there would be difficulty in confining the term, as has frequently been proposed, to roots arising on the shoot. Wettstein, therefore, classified all roots arising on the shoot as "Beiwurzeln" (*181*), but, as pointed out on page 28, this may lead to confusion in view of the very different way in which the same prefix is employed with the shoot. In this bulletin the qualification "adventive" will be used in a very general sense, meaning any root not arising in normal acropetal succession upon the young root. Indeed, brief consideration must be given first to normal root production, as the adventive root displays no special distinguishing characteristics whatever as regards its apical organization, and it seems that the same internal factors govern its production as govern that of the normal root.

In the dicotyledon the first root apex, organized in the embryo, must be regarded as essentially exogenous, although its subsequent development is characteristically endogenous, since the greatest activity in the construction of protoplasm and cell multiplication is shown by the layers of meristematic cells which border upon the differentiating stele. Just within the endodermal cylinder as it differentiates lies the pericycle, which is usually a single layer of cells in thickness and which frequently remains meristematic for a considerable time. Within the pericycle, at more or less regular intervals, local centers of greater meristematic activity appear, usually opposite the protoxylem, except in diarch roots, in which case the new centers appear in rows along the flank of each protoxylem group (p. 42). At a very short distance from the growing apex these may be clearly discernible as branch-root initials. Whatever the internal factors producing the greater meristematic activity in this region, it is frequently clear that their influence extends out beyond the endodermis, and in many cases the cells in the cortex opposite the protoxylem contain a greater amount of protoplasm and exhibit toward dyes a behavior which is different from that of the rest of the cortex (*142*). (Pl. 22, B.)

The production of the branch-root initial seems to be the natural response of the root type of apical organization to a plentiful supply of food in the presence of other internal conditions favoring increased meristematic growth. While in the shoot organization the corresponding conditions lead to the vigorous production of new folds of meristematic tissue upon the surface, in the root it is seen that such an increase of meristematic activity shows itself as pockets or groups of meristem which necessarily lie within the confining endodermis. Thus, even though the cells outside the endodermis may show a tendency to become densely protoplasmic along with other cytological changes, they never grow and multiply and hence do not contribute to the new apical meristem which ultimately pushes its way out through them.

The existence of these normal endogenous apices behind the main apex is very closely correlated with the properties of the pericycle.

The cells in this layer, as well as those in the other layers within the stele, ultimately vacuolate, and in some monocotyledons they may do this very early. Thus in Hyacinthus, for example, the cells of the pericycle vacuolate within a few centimeters of the growing apex, the cells opposite the protoxylem being the last to do so. So far there is no record of such cells ever returning to the meristematic condition. Although various experimental methods have been tried, so far no branch roots have ever been induced upon roots of this plant, and a number of other monocotyledons show similar behavior.

In other monocotyledons, according to Brenchley and Jackson (*16*, *64*) roots of two types are found with very different anatomical characteristics, the one kind branching freely and the other practically not at all. The same two types may also be present in some dicotyledons (*182*).[13] The anatomical characters that are associated with branching deserve further investigation. So far as examined, the branching roots seem to have the narrower steles and show the heavier lignification of the xylem; they frequently are earlier in forming a secondary endodermis and as a result shed their primary cortex earlier. They are, therefore, thin and fibrous, while the non-branching roots in the same plant are relatively thicker, white, and soft in texture.

Cocks[14] found with Camassia that when this bulbous monocotyledon was grown with its roots in water, they developed slowly, being thick and unbranched and packed with starch. Transference to relatively dry fiber produced a thinner, more freely branching type of root. Transference back to water again led to the formation of the thick unbranched type. Branching was induced in the thick unbranched region of the root by cutting off the tip and transferring the root to fiber. Cocks also found that the normal root type has a secondary or tertiary endodermis, with occasional passage cells, the swollen fleshy type a primary endodermis.

In those monocotyledons in which the root normally has the power of branching, probably even after vacuolation the pericycle may be able to return to the meristematic condition and give an adventive root initial as the result of wounding. Additional investigations by Cocks[14] suggest, however, that this happens only rarely in this group; on the other hand, it appears to happen frequently in the dicotyledons, provided that the injury consists only in the removal of a distal portion of the root, leaving the proximal portion, which regenerates the new root meristem, in contact with the shoot.

When a small piece of root system is completely isolated, the regeneration of new root meristems is certainly a very rare occurrence; however, if remains of old branch roots are present on the isolated portion, these will probably contain latent root initials which will now grow out. (Pl. 22, A.) Except for the type of organization of new root initials described for the fleshy root of Crambe, the production of new root initials upon isolated pieces of root appears to be a very rare occurrence, in marked contrast to the production of adventive buds.

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[13] Brown, F. M. V. The anatomy of marsh plants. Leeds, 1928. [Unpublished thesis.]

[14] See footnote 9 on p. 57.

In the older dicotyledon root, as already indicated, with the formation of two cylinders of interclary meristem, the pericycle ceases to play its all-important rôle in the formation of initials upon the main axis. Roots appear in the neighborhood of the vascular cambium, in the region of the primary rays, usually facing a protoxylem group. (Pl. 22, C.) Such a position reminds one of the position of the young root in the pericycle, but it is difficult to know whether at this stage the governing factor is the position of the protoxylem or of the ray; the close association displayed between root initials and vascular rays will be considered just below in relation to shoot-borne roots.

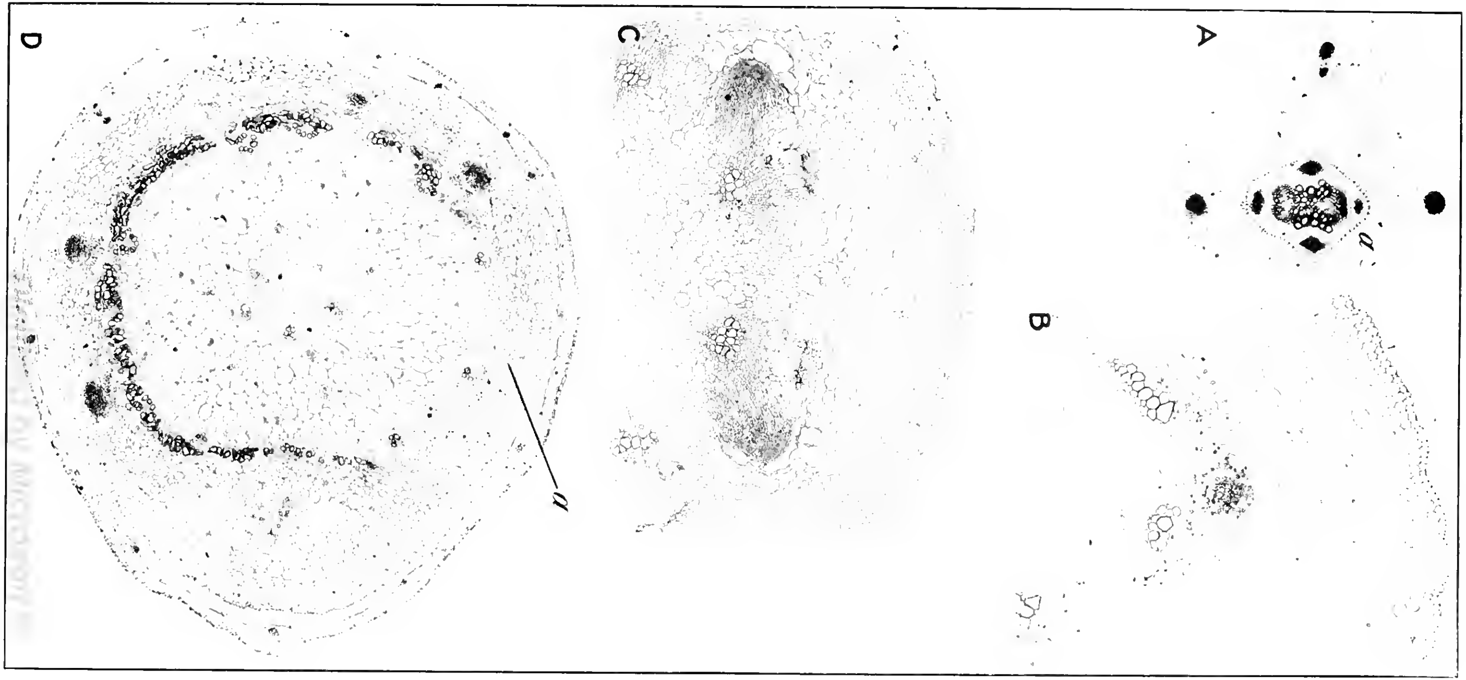
ROOTS UPON SHOOTS

The anatomical facts as to the place of origin of shoot-borne adventive roots are relatively simple and clear, but much confusion has been caused by failure to distinguish between the position of early formed roots and those formed later. Root formation in dicotyledon shoots may begin very early, indeed, even in the still-extending internode, in which case at first sight the position of the roots seems very different from the position of roots arising upon old stems which have ceased to extend longitudinally and in which radial growth alone is proceeding. Undoubtedly, however, there is a definite transition from one type of root origin to the other.

In the shoot, behind the apical meristem, vacuolation begins early in the pith and inner cortex, while between these two tissues is left a cylinder of dense meristematic tissue, the procambial ring. To either side of this ring cells are vacuolating and differentiating, but the outer and inner limits of the ring are bordered by the cells free from air spaces—on the inside the parenchyma, and on the outside the starch sheath; usually in water plants or underground stems and often in etiolated plants (pl. 23, A) the starch sheath becomes a functional endodermis (*141*, *118*).

As the vascular tissue differentiates within the procambial ring, the living cells, thus linked to the stele by a tissue free from air spaces, will receive a more adequate flow of nutrients from the supply within the conducting elements than will the cells farther removed. In the case of the xylem, the lignified elements have no semipermeable containing layer, and the liquid contents of these elements must be common to the walls of all this tissue. It is not surprising, therefore, to find that almost without exception new roots are always formed from tissues which are thus closely connected with the vascular supply. With root initials arising very early, when the procambial layer is young and has as yet not increased in girth, the usual position is in the cells lying just within the starch sheath—the pericycle, as it is often called, though in the stem the pericycle is much less clearly definable than in the root. Vascular differentiation usually, but by no means always, proceeds more quickly in those portions of the procambial ring which are immediately connected with differentiating leaf folds above. In such cases the new root initials practically always arise near, but to the side of, such a vascular group—that is, on a primary ray.

Root initials arising upon the young stem as in Lycopus, *Veronica beccabunga* L., and many others, are best described as pericyclic in position. Even in such a case, with a root appearing very early,



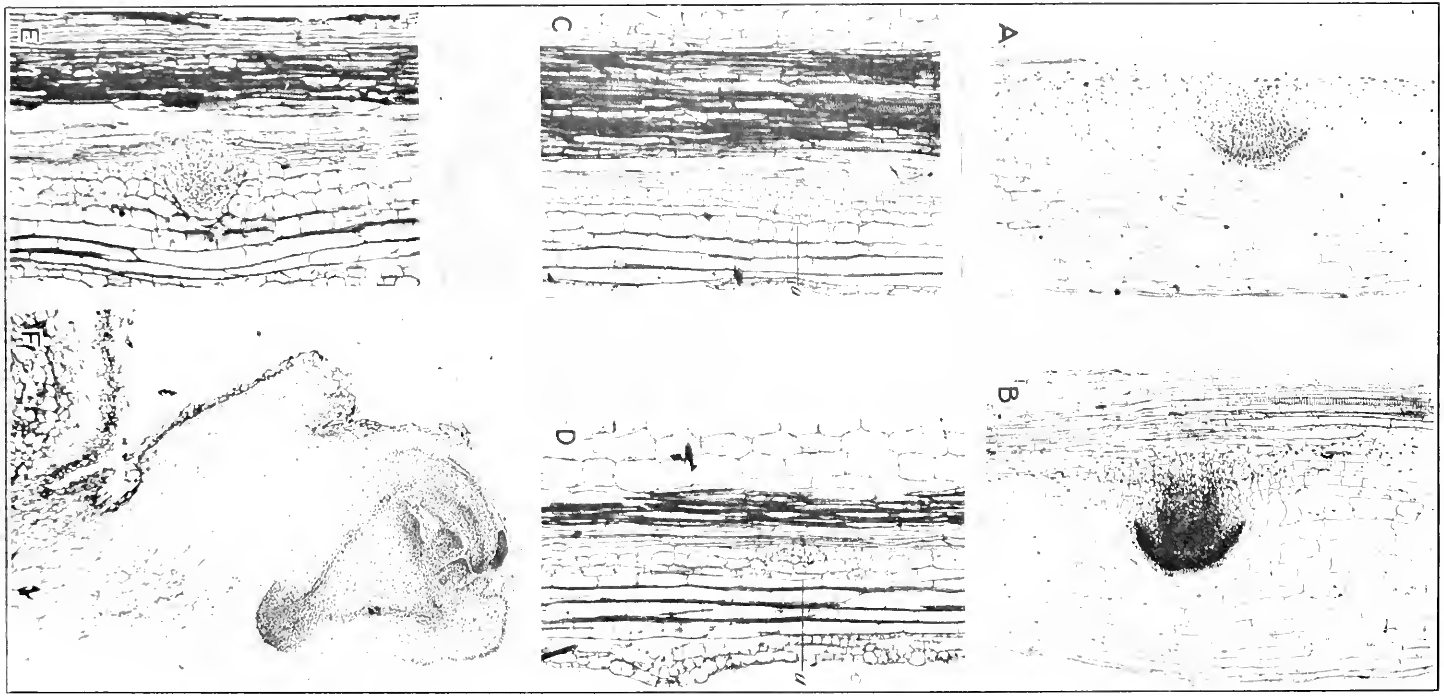
ADVENTIVE ROOTS ON STEMS AND HYPOCOTYLS (TRANSVERSE SECTIONS)

A.—Hand section of an etiolated shoot of *Pisum sativum*, heavily stained with safranin. At *a* the primary endodermis surrounds the narrow stele. This is not found in shoots grown in light. × 20.

B.—An isolated piece of hypocotyl of *Helianthus annuus*, taken near the proximal end. A young root initial is forming on the flank of one of the vascular bundles. × 60.

C.—An isolated piece of hypocotyl of *Ricinus communis*, taken near the proximal end and showing the formation of adventive roots on the flanks of two of the vascular strands. × 30.

D.—Young node of *Tradescantia fluminensis*. Several root initials are forming just outside the vascular ring. At *a* the procambial strands of an axillary bud are visible. × 20.



A and B.—Longitudinal sections through proximal ends of isolated pieces of epicotyl of *Vicia faba*, showing two stages in the organization of an adventive root. × 30.
C–E.—Longitudinal sections through the epicotyl of *Lycopersicum esculentum*, showing at *a* early stages in root formation in the pericycle. These sections were obtained from internodes left isolated from the plant for two days, but such root initials also develop in the intact shoot on the growing plant. × 20.
F.—Longitudinal section of proximal callus on a fleshy root of *Cichorium intybus*. An adventive bud with procambial strands is well developed at the surface but buried in the tissues of the callus; at the base of the procambial strands a typical root initial has formed, so that in this region the tissue organization is that of a typical embryo. × 35.

its origin is not to be traced to a single cell layer, much less to a single cell, for the cells at this position in the procambial ring remain or again become meristematic; thus a group is now organized as a root apex, its outermost layer in contact with the starch sheath, and its inner layer in close contact with the differentiating vascular elements.

But as the stem grows older, changes in the arrangement of the tissues occur. In particular, the activity of the cambium increases the width of the tissues in the region of the original procambial ring. During all or a part of the first year of growth, in spite of this increase in girth, the starch sheath remains a continuous barrier to the advance of air inward along the intercellular spaces from the cortex. But sooner or later at the outer end of the rays, the cells vacuolate and round off, and air spaces appear between them. According to Klebahn (*73*), such intercellular spaces are formed throughout the radial course of the ray and often provide a channel by which the aeration systems of pith and cortex are in communication, but in the neighborhood of the vascular cambium the cells are more recently formed and are more compressed, so that the intercellular spaces are relatively smaller and more frequently filled with sap. Under these conditions it is not surprising to find the site of formation of the new roots moving inward from the region of the pericycle to the living cells of the ray that lie close to the newly differentiated xylem and phloem. From this stage onward new root initials are thus found in association with the vascular cambium; they still arise in the rays and are still not organized from single cells, resulting rather from the organization of a group of the cells bordering upon the vascular cambium which have remained or again become meristematic, and which may be connected to the newly differentiated vascular elements by a tissue free from air spaces. Plate 23, C and D, and Plate 24, A to E, show various stages of root organization in isolated nodeless segments of the hypocotyls of Helianthus and Ricinus and the epicotyls of Vicia and Solanum. In Ricinus it is clear that meristematic cells have been constructed by every layer of the primary ray from cambium to outer layer of pericycle; in *Vicia faba* the new root apex has clearly emerged endogenously from within the starch sheath. In both cases new tracheids are differentiated at the base of the new root apex, which will link the vascular bundles of the axis with the new root.

In the light of this more recent developmental work (on other plants), the assumption made by the junior writer (*159*) that the stem-borne roots of the apple originate from single cells seems to be erroneous; undoubtedly here also the deciding factor is the organization of a group of cells rather than some definite change taking place in one single cell.

Van Tieghem and Douliot (*172*), while pointing out the common endogenous origin of adventive roots from stems, confined their studies almost entirely to roots arising before the differentiation of the vascular cambium, or at a stage but little later; however, they drew attention to this change in the placing of roots which occurs with increasing age of the stem. In fact, all work regarding root initiation seems to conform with the picture as just drawn, with the exception provided by the Cruciferae, which will be referred to below.

The apparently divergent statements found in the literature regarding the place of origin of stem-borne roots seem to offer no exception to the foregoing, but seem rather understandable on the basis that most observations have been made with very young stems (*172*, *181*); hence the statement made by Schüepp (*140*) is in apparent disagreement with the above. Furthermore, the fact that more than one layer of cells take part in the formation of the root has also led to a certain amount of confusion. The points that should again be emphasized are the pericyclic origin of roots on young stems, and the origin in the neighborhood of the cambium on older stems; in either case the roots are generally intimately associated with the rays; furthermore, their origin involves more than one layer of cells. This general viewpoint seems to hold equally well whether one is dealing with roots that grow out immediately after they have formed or with those that lie dormant for a lesser or greater period. In this latter connection see Trécul (*167*), Borthwick (*15*), Van der Lek (*86*), and Swingle (*157*).

Endogenous roots, though frequently more common in the neighborhood of a leaf insertion, may occur anywhere on node or internode. On the other hand exogenous roots, which seem to be restricted to the Cruciferae, occur only in the axils of the leaves, and are thus obviously associated with the axillary bud. This point was clearly brought out in Hansen's observations upon the origin of such roots in *Cardamine pratensis* (*52*). Here, the young root initial is found as a small protuberance upon the side of the base of the adventive, root-borne bud; it is clearly exogenous, the dermatogen in this region contributing the outermost layer of the rootcap of the newly organized root apex. While this group of meristematic tissue on the side of the bud thus organizes as a typical root apex, the part above develops the normal fold of the shoot apex, and the juxtaposition of tissues is such as is characteristic of the embryo, where meristems of both shoot and root are closely in contact and both exogenous. The organization of the root apex here is thus quite characteristic of a root, and all subsequent branches from this root are of the normal endogenous type. Once again it is seen that the distinction between root and shoot does not lie in their relative position of origin, but rather in their characteristic apical organization (p. 4).

The production of roots upon leaf cuttings is only a special case of adventive-root production upon the shoot and requires very little special consideration. In every case examined in detail by Regel (*124*), Hansen (*52*), Beinling (*12*), and Hartsema (*56*), the new root initials have been found to arise from parenchymatous tissue in close connection with the vascular cambium. Usually, therefore, such roots also are organized in the primary rays, though Hansen described them in Begonia as also arising occasionally from parenchyma that had been produced as callus tissue at the cut surface. Here again, the roots do not arise by the repeated division of any single cell from the cambium or any other one layer, but they result from the meristematic activity of a group of cells. Hansen stated that the calyptrogen first becomes recognizable and organization proceeds thence inward. This seems closely in line with the description and figures given of the organization of the root apex in the callus upon Crambe roots.

It will be remembered that root initials are formed on leaves much more readily than are buds, and indeed in many cases buds have never been obtained; if buds do arise, another crop of roots frequently arise from them in the normal endogenous manner, from the procambial ring of the newly organized shoot.

Adventive roots indeed arise very much more readily from shoots than do adventive buds, and the commonest method of vegetative propagation is the isolation of a shoot system with buds upon it, in the expectation that the cutting will root and become an independent plant. However, some plants root so uncertainly that this method of propagation can not be used in all cases. Thus many apples and many other fruit trees as well as a number of other hardwood trees form roots but rarely, while on the other hand the willow, the black currant, many varieties of apple, and many other plants (*42*, *86*, *175*) usually contain, as a normal thing, latent root meristems in the neighborhood of the cambial ring. In fact the difficulty in connection with root production from the shoot is not the statement of such simple anatomical generalizations as to their place of origin as have been given, but rather the correlation of these anatomical facts with the widespread divergence in behavior between different shoots. This problem is not a simple one, as is shown by the apple. Within this species there is a very great difference shown. The varieties that produce burrknots (*57*, *157*) contain as a regular and normal thing latent root initials which push outward into the bark and create the characteristic burrknots, while on the other hand very few varieties of apple have ever been rooted from ordinary hardwood or softwood cuttings. The recent papers by Graevenitz (*42*), Shaw (*143*), Vierheller (*174*), Yerkes (*188*), Auchter (*5*), Knight and Witt (*76*), and Maney (*93*) but emphasize this difficulty.

The papers just cited show that the problem thus indicated—the reasons for success or failure in rooting cuttings—is under vigorous attack from many angles. Therefore, in the hope of opening up some new avenues of approach to this important problem it seems worth while to analyze it from the anatomical standpoint more closely than has yet been done, even though such an attempt must necessarily be somewhat speculative. In making this attempt it has been possible to draw upon some unpublished anatomical investigations which were carried out in the Leeds botanical laboratory by W. A. Sledge and Elsie Briggs, and which, it is hoped, will be made more fully available later.

Factors Governing Root Production from the Shoot

AIR AND MOISTURE

In view of the characteristic apical organization of the root, root initials arising in the tissues of the shoot require ready, and therefore close, access to the vascular supply. Usually no air spaces exist between the meristem and the source of food, any intercellular spaces being injected with sap, so that the walls between the cambium and the meristem remain saturated and thus permit a steady diffusion of solutes. On the other hand, oxygen is necessary for the respiration of the newly organized meristem, though, as Swingle pointed out (*162*), some species are much more tolerant of oxygen deficiency than others. Probably this oxygen reaches the meristem mainly through the wider intercellular spaces of the cortex, which usually remain uninjected. The practice of clearing the latex from the base of cuttings of plants containing laticiferous systems (*152*) may possibly find its justification in the freedom of the cortical air spaces thus insured.

The balance between injection of the intercellular spaces behind the newly organized root apex and the free movement of air in the spaces in the cortex beyond it, is obviously a delicate one in the case of sensitive cuttings. Horticultural practice often prescribes in such cases that the base of the shoot should be rammed firmly against the side of the container. This should bring about at one and the same time aeration of the wider cortical intercellular spaces, because the cutting has a pocket of air around its base, and injection of the narrower intercellular spaces in the neighborhood of the vascular ring because of the response of these parenchymatous tissues to the pressure employed (*67*). Such a treatment may, therefore, be of very material significance in the case of quick-rooting herbaceous material; it is hardly likely to be effective in the case of slow-rooting hardwood cuttings. The difficulty frequently experienced in rooting cuttings with a large pith may be due to the fact that in such stems the air in the pith within the vascular ring may make it difficult to keep the intercellular spaces in the rays injected in the region of the cambium, and it may in some cases be avoided by using cuttings with a heel (*152*). Similarly, in experiments in which liquids are injected into the vascular system in the effort to assist root production (*27, 76*), where the pull is applied at the distal end (as by the transpiring leaves themselves), it is transmitted downward through the xylem alone, since the cortical air spaces are in ready contact with the outside air. Thus by this method the xylem and the tissues just bordering upon it are alone injected; on the other hand, when the same difference of pressure is used to drive a liquid in from below, the air in the cortex is easily displaced by the entering liquid, and thus any special meristematic activity in the region of the cambium would most certainly tend to be subjected to oxygen deficiency.

Swingle's experiments (*162*) have shown conclusively that the aeration conditions which are optimal for root production are not necessarily, if ever, identical with those which are optimal for callus production, although callus production has often been treated as synonymous with root production. In all cases examined callusing seemed to demand the presence of less oxygen than did rooting, in many cases actual inhibition of callusing being observed while rooting progressed apparently normally.

Corbett (*25*) emphasized the difference between rooting and callusing, and Balfour (*7*) showed that in some cases root production could be brought about by paring down the bulk of the excessive callus originally produced. In the detailed discussion of callus and meristematic activity at the distal end of the roots of Crambe, it was made clear that the cell proliferation and division in callus production and the meristematic activity of the phellogen which produces cork near the surface of such a callus were distinct from the subsequent deeper lying meristematic activity which was more closely associated with root production. Therefore, the removal of the superficial layers of callus may remove another meristematic tissue which is drawing upon a limited food supply, and leave more food available for the meristematic activity, associated with the vascular cambium, in connection with which roots are organized.

LIGHT AND ETIOLATION

Light certainly has little influence upon the development of the endogenous meristems at the base of a cutting, and usually it seems to have little influence upon the subsequent growth of the root apex (*116*), but it has been seen to favor the initiation and growth of any superficial shoot meristems which may be competing for the available food supplies of the isolated shoot (*41*). It seems, therefore, wiser to exclude light from the basal region of the cutting on which root production is desired. Still more important, however, may be the previous etiolation of the region of the shoot from which, at a later date, when isolated, root production is desired. The consideration of this problem requires a brief digression into the subject of the growth organization of the normal shoot.

The shoot growth unit.—As Beijerinck (*11*) pointed out, when root initials are present or can be induced experimentally, they are usually distributed around a leaf insertion, sometimes in the leaf axil, but more frequently to either side of it and a little below it. To this extent their occurrence is in accordance with Chauveaud's conception of a "phyllorhize" (*23*) or Celakovský's, of the "Sproszgliede" (*21*); that is, a section of the axis with its attendant leaf forms a natural growth unit, made up of a leaf and a portion of the axis below down to the insertion of the next leaf vertically beneath. This growth unit, it is argued, should naturally terminate at this point in a root initial. Thus in a simply organized vascular plant, as the sporeling of Ceratopteris, successive leaf-root units are formed; each bears on its ventral surface, in its turn, a growing point which gives rise to a similar new unit. The axis of this fern is thus built up of these merged contributions of the successive "phyllorhizes," while the roots do not form a separate branching system but arise at the base of each successive "leaf-shoot" unit.

In the dicotyledon, Celakovský and Chauveaud, among others, have given reasons for regarding the shoot axis as still built up by the fusion of similar successive growth units, only in this case the root is missing at the base of the unit, where it meets the insertion of the next leaf below. But Beijerinck's observations (*11*) have emphasized the fact that the adventive roots ("Beiwurzeln") appearing on the stem do usually occur in this position. Why, then, are they sometimes missing, and why does every effort to induce their formation in this position meet with failure? One possible answer is that at this point, where the shoot unit meets the shoot unit next below it, a new meristematic center is now invariably present which may draw upon the food supplies that would otherwise be available for the root; this is the axillary bud, a competing meristematic center that is not met with in most of the vascular cryptogams.

Further, in the dicotyledon, instead of the "phyllorhize" habit of growth, with root initials formed near the termination of each unit, the food materials move downward toward the main root system at the base of the shoot axis, which remains continuously active throughout life, new crops of roots being formed upon the scaffold roots from the food supplies brought down from the shoot. This difference is undoubtedly correlated with the change of organization rendered possible by the development of a vascular cambium. The layer of new vascular elements thus added to the axis throughout its length each spring, puts the new shoot units at the periphery of the branches of the axis into effective communication with the new root system similarly developing at the peripheries of the root system. Therefore, even when the supply of food at the base of a potential "phyllorhize" is not used in the organization of an axillary shoot, instead of being diverted to root organization at this point it may move on downward in the continuous chain of vascular connection constructed by the cambium.

In these few words a very complex and controversial morphological and phylogenetic problem is just touched upon, further information in regard to which may be obtained in a monograph by Chauveaud (*23*). It has been discussed primarily because of the suggestion that immediately follows as to the significance of etiolation, but it seems probable that considerable significance may be attached to this growth-unit conception in the interpretation of the physiology of the shoot.

Etiolation prior to cutting.—Darkness certainly inhibits the superficial meristematic growth of the shoot apex. Internodal extension, in connection with existing leaf-shoot units, may take place vigorously, but no new growth units form, and if the meristematic apex is but slightly organized, as in the embryonic epicotyl of an epigeous seedling, in darkness it makes little or no further growth, and the hypocotyl alone extends until the food supplies of the seedling are exhausted, the epicotyl never emerging from between the cotyledons (*115*, *118*).

Similarly, at the East Malling Research Station, Director R. G. Hatton and his associates have had marked success in obtaining roots upon fruit-tree layers which root with difficulty by keeping the new shoots etiolated for several centimeters; however, they found it necessary to compromise between number of shoots and freedom of rooting. Although the shoot which has been continuously etiolated roots by far the most readily if the buds are buried, even though but a thin covering of earth is employed and even though this is not put on until just before visible activity of the buds is to be expected in March, nevertheless decidedly fewer shoots per stool are obtained than when the covering of soil is applied some weeks after bud break has occurred.

Likewise, Knight and Witt (*76*), working with plum and apple, Reid (*126*), and Blackie, Graham, and Stewart (*13*), working with camphor, Smith (*146*, *147*), working with clematis, and Priestley and Ewing (*118*), working with broadbean, have recorded a considerable enhancement of the capacity of the shoot to root through etiolation, a fact which has been on record since very early times (*33*). In all such cases the development of the young axillary shoot meristem is retarded by darkness, and frequently under these conditions food which might have been utilized in its growth appears to be employed in the organization of root initials in the neighorhood of the cambium. However, the presence of a functioning assimilatory region above the etiolated part seems to be desirable in most of these cases.

Various other suggestions have been made as to the significance of etiolation of the shoot prior to its removal for purposes of propagation. Priestley and Ewing (*118*) pointed out that in the epicotyl of *Vicia faba* and other hypogeal seedlings, etiolation led to the production of a primary endodermis in place of a starch sheath, a change which, as has been seen, tends to favor endogenous growth activities as against exogenous. Reid (*126*) and Smith (*146*, *147*) drew attention to various histological changes that certainly would favor the emergence of rootlets though it is not clear how such changes would influence their initiation. Knight and Witt (*76*) found that etiolated cuttings of Prunus produced most of the roots laterally; these were the "morphological" roots of Van der Lek (*86*), while without previous etiolation the few roots obtained almost all emerged through the wound callus.

The general considerations just advanced increase the significance of these recent observations and suggest that etiolation of the shoot prior to its removal for purposes of propagation (i. e. partial layerage) is a line of experimental attack worthy of considerable physiological and anatomical attention.

THE HARDWOOD CUTTING

Other recent extensive series of experiments upon the propagation of cuttings are at first sight apparently in direct disagreement with the generalization just attempted. From the standpoint of the preceding paragraphs, the development of the axillary buds may be a definite contributing factor in the failure of the shoot to root. Van der Lek (*86*) concluded as the result of a very extensive series of experiments that the development of roots upon hardwood cuttings—that is, woody twigs with dormant buds and no leaves—is materially favored by the development of the buds. However, generalizing from Van der Lek's experimental results requires caution. As Swingle has already pointed out (*162*), the further development of preformed roots of burrknot apples was affected but slightly, if at all, by the presence of buds upon the cuttings. The general question of the relation of bud start to the initiation of root apices on the stem beneath deserves further examination.

CAMBIAL ACTIVITY AND ROOT PRODUCTION

Apparently, the cambium furnishes the connecting link between activity of the bud and the initiation of new roots. As has been seen, the new root initials are always formed in tissues in close association with an active cambium. During the winter months the cambium of the branch is usually in a dormant state, and upon the tree in the spring cambial activity begins beneath each bud and works thence downward along the stem (*47*, *156*). This seemed to suggest a ready explanation of the observations of Van der Lek

(*86*) and of the correlation often reported by others between bud activity and root production, especially as a similar renewal of activity beneath the buds on willow cuttings, which then spreads basipetally down the cutting, has already been recorded by Hartig (*55*). But an anatomical examination of the question shows that it is not so simple.

When a piece of shoot is isolated, although but slightly less callus may form at the distal end than at the basal end, cambial activity itself seems to be confined to the basal end of the cutting. Sledge[16] found that this renewed activity spreads slowly up the stem, but usually cambial activity is also working downward from breaking buds higher up on the isolated shoot. Examination of such cuttings at frequent intervals has revealed much material in which there is a neutral, dormant zone lying between the pushing buds and the active basal region. At the base the cambium at first frequently forms wood of the "wound wood" type,[17] but in some cases the wood is indistinguishable from the normal wood. After the cambial activity has become continuous throughout the shoot, the wood formed throughout is of the type usually characteristic of the stem.

These observations render it impossible to ascribe in all cases the advantage of the presence of buds to the start thus given to the cambium. Cambial activity at the base is certainly essential to root initiation in this region, but the activity may be quite independent of the bud, as indeed is shown very clearly by experiments with internodal cuttings carried out in winter with short shoot pieces in which the cambium is still dormant. In practically every case of this kind, Sledge[16] found that cambial activity was initiated at the basal end of the cutting.

It seems necessary to reserve an opinion as to the relation between bud development and root initiation. Van der Lek's cuttings were under unusual conditions, being exposed to the light in a very moist atmosphere. Under these circumstances probably even the basal buds would commence activity, and the cambium activity thus initiated would soon affect the root initials beneath it, or, as in the grape cuttings, the tissues disposed toward root formation. With cuttings which have several basal internodes buried in the sand, the lower buds rarely develop; usually cambial activity, and often rooting as well, will commence at the base before this cambial activity is linked with that working down from the pushing buds. For continued root development a shoot system developing in the light is essential, but the connection between the just-emerging bud and root initiation at the base of the hardwood cutting is far from firmly established.

Interest seems rather to be transferred to the conditions governing meristematic activity in the neighborhood of the proximal wound and that delicate internal balance which converts this activity from the production of ordinary new vascular tissue to the organization of root growing points. Almost certainly one essential for the resumption of cambial activity is the displacement by sap of the air in the

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[16] SLEDGE, W. A. Unpublished research at University of Leeds.
[17] The writers' attention was first drawn to this point by Dr. R. C. Knight, of the East Malling Research Station.

intercellular spaces in the neighborhood of the cambium. Sledge[19] found that if sections cut from woody shoots just before and just after resumption of cambial activity in the spring are transferred directly from the knife to strong glycerin, a marked difference in the appearance of the tissues will be noted in the two cases. Sections cut before the resumption of cambial activity appear dark with the trapped air contained in the vascular rays, even in the cambial region; but as activity begins, the whole of this region becomes translucent throughout, and air is confined to the inner part of the wood, the pith, and the outer regions of the phloem.

When the dormant twig is cut out of the tree, the narrow intercellular spaces near the cambium will become injected with sap; this is one response of the delicate living tissues in this region to the shock. At the distal end this condition does not seem to persist, and everything points to a rapid drying back of the sap from the neighborhood of the cut surface in many twigs until the neighborhood of a node is reached. At the basal end this condition of injection seems to persist whether the cut surface is nodal or internodal, and as a result cambial activity is initiated.

Here, once again the difficult problem of polarity arises, and it is impossible at the present time to evaluate the part played by the phloem and the other tissues in thus maintaining the conditions for cambial activity at the proximal end. This problem will be again considered in connection with the influence of metabolic factors upon the initiation of roots. First of all, however, the specially difficult case of the scion apple must receive brief examination.

The propagation of the apple.—In many unsuccessful trials at Leeds and at Washington with the apple the cuttings either rotted or dried out. Rotting is understandable in these cases in view of the fact that suberization of the cut surfaces is often very irregular in the pith region. Frequently a well-callused base of such a cutting shows a hole in the center of the callus, leading into a disorganized pith. If such a cutting does not root within a reasonable time it is almost certain to decay. In fact, with older cuttings containing burrknots the cut base in many cases rots because of ineffective healing of the cut surface, even though roots may have long since appeared.

On the other hand, the drying out of the twig means that the cambium layer is certainly unable to continue to function, for the tissues in its neighborhood are no longer injected with the necessary moisture. (See the note regarding the propagation of the hop on page 56.) Examination of such cuttings usually shows that the cambium had commenced activity at the base, and frequently this activity has exhausted the starch throughout the entire cutting. In such cases the starch usually disappears from the cutting from the base upward, instead of from the pushing bud downward, as happens when the shoot is left on the tree (*156*). This depletion of the food reserves may be a very important contributing factor in the failure to produce roots. In this connection Winkler's work (*184*) on the relation between starch content and root production in the grape cutting is important.

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[19] See footnote 16 on p. 70.

Cambial activity commences at the base of the shoot, and thus are produced differentiating xylem elements which, if protected beneath by a suitable callus material, will act as an osmotic system and draw water from the soil around the base of the cutting. Examination of the withered cutting clearly shows that the sap movement has not produced its usual effect. Either leakage away from the wood through the disorganized pith on the inside or a certain lack of effectiveness in the system of differentiating xylem and basal callus seems to be responsible. The writers' attempts to remedy this defect by sealing the base of the cutting did not prove effective.

Some of the difficulties of cutting propagation are avoided by the employment of the nurse-root method (*5, 143*). This method involves the grafting of a piece of stock root upon the base of the scion that roots with difficulty. In some cases the scion is buried very deeply in the ground in the hope of getting roots upon this original piece, while in others short scions are used, and the root system is obtained at the base of the new growth. The root system of the cutting is thus in either case at first furnished by the easily rooting stock, but with many varieties after a year or two roots develop upon the scion; the nurse root can then be removed from many of the cuttings, and the rooted plant can be replanted as a complete tree. The chief difficulty offered by such a method, however, is the greater relative development of stem than of roots upon the scion, so that the scion when removed has insufficient roots to maintain it. In this system of treatment the difficulty of maintaining a sap supply in the scion is met by the vigorous growth and root production of the nurse root which absorbs ample water from the soil and delivers it to the scion. At the same time disorganization and decay at an imperfectly blocked pith surface in the scion are avoided by the presence of the graft union.

Auchter (*5*) emphasized the need for deep planting. Such deep planting will obviously materially aid the nurse root in the task of keeping the scion tissues well supplied with sap and at the same time will favor meristematic activity in the cambium rather than in the bud.

However, the problem is by no means solved. Root production on the scion depends not only upon a vigorous cambial activity but upon an abundant supply of elaborated materials in the neighborhood of the cambium. Much of this material will move down out of the scion tissues into the stock, where vigorous root production takes place. To some extent this movement may be checked at the base of the new growth, where a wire ring is sometimes applied for this purpose, or at the point of the graft union; nevertheless the drain of the stock-root system upon the supply of elaborated food will materially reduce root production in the scion.

In this connection Chandler's (*22*) modification of the nurse-root method is of great interest. He grafted the stock-root piece into the side of the scion so that a short piece of the scion projected below the union. The result was that materials to some extent moved past the point of union down into the stub of the scion; here root production took place, sometimes laterally, in some varieties mainly through the callus formed over the base of the stub; in a very few cases roots also formed above the union. The success of this method suggests that, provided the scion is kept supplied with abundant sap, suberization and callus formation at its exposed base will be satisfactory, and root formation from the wound callus is thus added as a possible method of root formation.

However, this method seems to have one very serious if not fundamental drawback. These conditions are extremely favorable for the production of what have long been called crown galls. Even though the recent work of Riker and Keitt (*128*) seems to indicate that such overgrowths are not so serious as has long been thought, they are at least undesirable.

If by the devices indicated the cambial region in the isolated shoot system can be kept full of sap, the result seems likely to be continued meristematic activity and thus in time the production of roots. This may also be the explanation of the successful rooting of softwood cuttings of apple, reported by Stewart (*152*). In such a shoot, as has been seen (p. 62), air is prevented from approaching nearer the cambium than the outer wall of the starch sheath, and when such material is severed for propagation it at least starts with the tissues well provided with sap. In fact, one of the most commonly used criteria for ascertaining that the shoot is in proper condition for use as a softwood cutting is a state of high turgidity; the desirable shoot usually breaks off clean when bent, and the unsuitable shoot collapses and crushes.

Unfortunately, none of these methods or that of root-cutting propagation described by Yerkes (*188*) has the simplicity or certainty requisite for extensive employment in the commercial nursery, although a variety of methods are available which may enable the investigator to obtain scion varieties of apples upon their own roots. For the nursery practice at present the only method seems to be grafting either upon stocks grown from seed or upon vegetatively obtained layers or root cuttings.

THE SOFTWOOD CUTTING

In the softwood cutting the shoot is taken at a time when its leaves are still functioning. There is some disagreement among practical horticulturists as to the rôle played by the leaves in the propagating frame, since the most obvious effect of the leaves is their tendency to dry out the cutting. Hence, the more leaves remaining, the more saturated must be the atmosphere within the propagating frame in order to avoid draining the sap from the neighborhood of the vascular ring, where its presence is all important for root production. Provided this contingency can be avoided, the presence of the leaves seems highly desirable, since the older leaves, in the light, continue to supply a considerable amount of food to the axis. The quantitative studies of Loeb (*90*) on Bryophyllum give some indication of how important the leaf may be in this connection, and in such herbaceous cuttings the relation between rooting and the downward movement of materials from the leaf through the vascular channels is much more evident than in the case of hardwood cuttings.

From the time the procambial ring first shows its close connection with the leaf initial, cambial activity is obviously closely allied to the growth of the leaf. In the shoot the first tangential divisions initiating cambial activity in the procambial strand follow close upon, if they do not actually precede, the earliest signs of vascular differentiation. Jost (*70, 71*) has shown that this process of cambial division is greatly dependent upon the growth of the lateral organs, whether leaves or flowers, above it on the axis. His experiments with the epicotyl of the seedling make it clear that the controlling factor is not the food supplied by the cotyledons lying below, but rather the actual growth processes occurring in the young lateral initials above.

In the twig, the subsequent dependence of cambial activity upon growth processes in the bud seem to be only a continuation of the same phenomenon. In experiments with decussate-leaved Coleus, using isolated pairs of internodes with one single node between them, it is easy to see that great influence was exerted by the growing leaves, both upon ordinary cambial activity and upon root production in the axis beneath. Here again the factor affecting growth was not simply food supplies; although the entire basal region of such cuttings is usually gorged with starch, nevertheless cambial activity and root production lag behind on the flanks of the proximal internodes which are not subtending a leaf. Plett (*109*) [20] in his experiments with internodal herbaceous cuttings noted an accumulation of the starch toward the proximal end of these cuttings in many cases, especially in Begonia, *Sanchezia nobilis* Hook., and *Sinningia purpurea* Hort. In these cuttings and in others in which some leaves were left, starch accumulation often coincided with greater rooting, but Plett also found an influence of the bud upon root formation in the internode below, which seemed quite independent of the localization of food supplies.

The basal movement of the carbohydrate contents, as indicated by starch distribution, in such internodal cuttings may be very striking. In some of Briggs's observations upon isolated nodes of Coleus the congested appearance of the phloem in this basal region certainly suggested that it had taken a part in the movement. Greenwood [21] also found that if isolated shoots of Pelargonium and other herbaceous cuttings were ringed, cambial activity began at the proximal surface above the ring, as well as at the basal end of the cutting. In some cases there was also distinct evidence of a greater depletion of carbohydrates from the upper end of internodal cuttings and some indication of starch accumulation at the basal (proximal) end.

If the direct course of the vascular channels beneath a leaf is broken by a cut in which a mica slit is inserted, then within a few days root production and cambial activity can be diverted to another flank in these plastic tissues. Anatomical investigations made by Simon (*145*) and confirmed by Miss Elsie Briggs, show, however, that this diversion is preceded by the differentiation of new vascular strands on the other side of the stem.

The evidence is, therefore, again very strong for associating root initiation with cambial activity and this once more with the activity of the leaf and probably with the transmission through the phloem of some substances which accumulate in the region where roots are ultimately produced.

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[20] See footnote 6 on p. 31.

[21] GREENWOOD, L. THE PROBLEM OF POLARITY IN ISOLATED PIECES OF STEM AND IN INVERTED GRAFTS. Leeds. 1927. [Unpublished thesis.]

Sledge[22] has observed in internodal cuttings of privet, apple, and other plants that after a time definite evidences of disorganization, which apparently begins in the phloem, are visible at the distal end. Early signs include a swelling and vacuolation of the phloem parenchyma cells, accompanied by a gradual disorganization of their nuclei, following which the cells of the cortical parenchyma frequently swell and discolor. This change is always associated with a very marked alkalinity of the tissue. The reaction is very definite and sap diffusing from the phloem is as alkaline as pH 8. These observations suggest a continued basal movement of substances in the phloem which may ultimately result in a disorganization of this tissue at the exhausted distal end, in which, when carbohydrates fail, respiratory metabolic activity leads to the destruction of protein with consequent nuclear disorganization and the development of an alkaline reaction. The continued downward movement of substances through the phloem may at least be a contributory factor to the polarity of the isolated shoot segment and the partial cause of the accumulation of carbohydrates at the proximal end. The relation of such an accumulation to subsequent root initiation is indeed difficult to determine. Such carbohydrate accumulation has to take a particular form; possibly the development of a relatively acid reaction, which is often associated with a high carbohydrate-nitrogen ratio and a diminished degree of succulence (*103*, *63*), is a necessary condition.

Reid's (*125*) observations on the effect of the carbohydrate ratio on the rooting of the tomato are direct experimental evidence of a nitrogen correlation which is generally recognized, and which is the partial explanation for the restricting of initiation and development of roots above a ring extending into the cambium and above ligatures constricting the bark. Such a relative increase in carbohydrates is probably associated with rooting in the pendulous tips of certain varieties of Rubus in the later part of the growing season, in the drooping stolons of *Cornus californica*, and is probably the factor linking flower-bud and burrknot formation in the apple (*157*).

Temperature may exercise a very definite influence upon root initiation by its influence upon the balance of metabolism. Bushnell (*19*), analyzing the potato plant as affected by temperature, shows that carbohydrate accumulation in the plant increases rapidly with a fall in temperature, supposedly because, although photosynthesis may have a comparatively slight temperature coefficient, the utilization of sugar in respiration diminishes very rapidly with a fall in temperature. This brings to mind an interesting comment upon the early observation of Vöchting (*177*), confirmed by Bushnell, as to the geographical distribution of the potato: stolon and tuber formation is favored by low temperature and leafy-shoot production by higher temperatures. From such an effect upon the metabolic balances of the plant, lower temperatures might similarly be expected to favor root production, while on the other hand with a rising temperature, exudation pressures, which depend upon growth and differentiation and which are intimately connected with the maintenance of shoot meristems, are likely to be greater. This is

[22] See footnote 16 on p. 70.

an almost unexplored field. Beijerinck (*11*) recorded the observation that the apple and the pear produce root-borne buds (suckers) more readily in a warm climate. Likewise in the fruit trees of Europe many observations suggest two maximum periods of root growth, one in the spring at the expense of stored food reserves and the other in late summer or fall after foliage production has reached its maximum (*106*).

However, accumulation of carbohydrates does not necessarily mean the production of conditions favorable to root initiation. Plett (*109*) [23] found it necessary to distinguish between the accumulation of starch at the base of an internode and the production of roots from this region. There is indeed a good deal of evidence which suggests that in particular the presence of starch should not be regarded as a necessary indication of a disposition to produce roots. Ahrns (*2*) showed that in an isolated leaf system starch is only retained or produced under certain conditions, even when the carbohydrate content is very high. Thus, if the leaves are allowed to lose water and wilt, the starch rapidly disappears and the sugar content in the mesophyll greatly increases. On the other hand, if the leaves are kept saturated with water, the starch, even in the dark, disappears very slowly and the sugar concentration remains low (*111*). Starch appearance in this condition, therefore, seems to be an indication of a condition of high hydration of the tissues, and it may be recalled that, when dealing with root production from roots, the swollen starch-filled root was associated with an indisposition to branch. In the case of the shoot similarly the consideration of one striking case in which high carbohydrate content does not necessarily involve a ready disposition to root, may conclude this section.

A TYPICAL CONUNDRUM (THE POTATO TUBER)

Probably the reader requires no further reminder that these pages represent only the effort to state a problem and not the attempt to justify a solution. The production of roots upon shoots bristles with difficulties in the way of any generalization, and the tentative efforts made above seem likely to be shipwrecked by such a homely object as the potato. The tubers of the potato are in part the products of cambial activity, and they contain a cambium capable of further meristematic growth. Very abundant food reserves, especially carbohydrates, are present; and they also have both internally and externally a very widely distributed phloem, very parenchymatous it is true, but with sieve tubes ramifying through it. Yet from the tissues of the tuber itself, notwithstanding numerous experimental treatments, apparently there has not been obtained one authentic case of root production. The same seems to be true for tubers of certain species of Dioscorea (*176*).

Although cambium, carbohydrates, and phloem are all present, conditions are still definitely unsuitable for root production. On the other hand, in the stolons an endodermis is present, and endogenous roots are produced with exceeding freedom. Cases where roots seemed to emerge from the tubers have, on examination, proved to be cases of roots arising from the bases of stolons not completely

[23] See footnote 6 on p. 31.

freed from the tuber, or (*135*) from the point of insertion of the tuber upon the parent stolon.

As the end of the stolon swells and the new tuber forms, the endodermis disappears, and a cork phellogen begins activity, at first in the epidermis and later in the subepidermal layer. Thus the formation of the tuber is associated with a superficial meristematic activity, which, however, is not followed by free bud production, for the regeneration of buds from the tuber, though occurring from wound tissue occasionally, seems to be usually limited to the neighborhood of the eyes. In the resting tuber probably the intercellular spaces in the cambial region, as elsewhere, are filled with air; with the outgrowth of the buds the cambium may temporarily become active again, but root production does not follow. A certain vague correlation is here suggested between the failure of root formation and the swollen, starch-packed, unlignified, unbranched root. Evidently food supplies are abundant, but at no stage of depletion do conditions become propitious to the initiation of new roots.

This case seems worth its position at the end of this account of root production on the shoot, if only to show how far still is the interpretation of the phenomena from being complete. It is obvious that the problem of root initiation is far from settled.

ADVENTIVE EMBRYOS

Although both adventive roots and adventive shoots have been considered in some detail, a few words must be said about the appearance of these two structures when they arise together, even though at the present time the employment of adventive embryos as a means of growing uniform plants seems more an alluring vision than a definite promise.

As is too well known to stress here, with very many plants the desirable features of vegetative propagation as compared with seed propagation are more than offset by the great difficulty of handling. Hence the prospect of combining the desirable features of vegetative propagation with the ease of handling characteristic of seed propagation, is indeed inviting. It has been known for many years that one type of polyembryony is characterized by the formation of embryos, by tissue of the nucellus, which genetically represents only the seed parent. These embryos push into the embryo sac and compete for space and food with the true embryo. Apparently in most cases the true embryo wins the struggle; hence the rarity of development of the asexual embryos makes it almost impossible to recognize them when they actually do appear.

Recently, however, Frost (*37*) has called attention to the fact that in certain citrus hybrids the true embryo is apparently always crowded out by one or more complete adventive embryos, so that in these cases "vegetative reproduction by seeds" is achieved. Such facts regarding the occurrence of this phenomenon as are known are chiefly genetical in nature, and apparently nothing at all is known regarding it from the standpoint of causal anatomy.

Attention has been called (*77*, *161*) to another type of asexual seed production which is apparently not dependent upon the stimulus of fertilization as were the cases referred to by Frost (*37*). Kobel (*77*) found that unfertilized flowers of apple set seed under conditions not at all understood and pointed out the importance which such asexually produced seeds would have for use as grafting stocks.

If such a use of terms is permissible, it may be said that Plate 24, F, illustrates a still more asexual type of adventive-embryo formation, but one which does not seem to have the importance possessed by the two types just referred to. In this case of *Cichorium intybus* apparently a bud has arisen on the callus tissue around a branch root (p. 47). However, instead of the procambial strands differentiating backward through the callus, and ultimately connecting with the vascular supply of the main root, a root growing point has arisen just behind the bud and in such a position as to suggest that the two structures differentiated in the callus simultaneously. Here again nothing can be said about the causes underlying such a remarkable deviation from the course of events usually shown, but shoot and root initials also develop in equally close juxtaposition in the axillary buds of many of the Cruciferae (p. 64), where, just as in the true embryo, the root initial associated with the bud is organized in an exogenous position, though its subsequent growth is of the usual endogenous type.

DISCUSSION

THEORY AND PRACTICE

No attempt has been made in the previous pages to describe exhaustively the wide range of phenomena that are covered by the term "vegetative propagation." Not only do these phenomena differ as to position and mode of growth of the adventive structures concerned, but there are endless differences of details as to the time these growths take to form, and their response to season. Any effort to enunciate a general law governing these phenomena, therefore, meets with the almost inevitable sequel that, from among the multitude of slight individual variations, some example is forthcoming which appears, in its behavior, to refute the generalization.

So impressed are some of the most experienced workers in this field with this aspect of the problem that they incline toward the idea that the only adequate generalization is that each plant, or at least each species, is a law unto itself and requires individual study before its behavior as a self-propagating unit can be determined. There is obviously a substratum of truth in this standpoint; the test of practical experience alone will determine the method of propagating a new species, but if this view is exaggerated it becomes the negation of science and discourages all effort to ascertain the biological framework common to a group of plants which are universally recognized as forming a natural group. Throughout the previous pages, therefore, an effort has been made to present the varied phenomena from a consistent standpoint, but with as little consequent distortion as possible.

Both botany as a descriptive science and horticulture as, to a large extent, systematized and recorded practice, tend to be smothered under a mass of detailed observations, which convey no message because they have not been brought into contact with any generalized statement of the problem of plant growth and behavior. Therefore, in the writers' opinion, there would be no justification for this restatement of the problem of vegetative propagation from the standpoint of anatomy, if it were not associated with an effort to combine the facts into some working hypothesis regarding the factors controlling growth and development. Such a working hypothesis has been found in the suggestion as to the internal factors controlling the normal growth and development of shoot and root. All the varied phenomena of adventive shoot and root production that have been considered, have been briefly interpreted as they came under review, from the standpoint of the internal conditions assumed to be necessary for the production and maintenance of the "normal" activity of a meristematic apex. Undoubtedly this interpretation will need modification as the infinitely varied details of these complex processes are rendered available by further investigation, but at least it provides a standpoint which should promote rather than hinder fuller inquiry, and it is certain that in such further examination more light will be obtained upon the little understood phenomena governing normal growth.

Since any working hypothesis that is to justify its existence should open new avenues of inquiry, it is desirable not merely to examine the recorded facts, but also to consider whether the standpoint adopted adds anything to the interpretation of the complex interrelations existing between the internal phenomena of propagation and the contributing external factors. This brings the observer into the very diversified record of practical experience, where, owing to the almost inevitable horticultural method of varying several external factors at once, generalization must be cautious and tentative.

It may be emphasized that the experienced horticulturalist who claims that every species is a law unto itself implicitly displays in his procedure as determined by his experience, a system of wide generalization as to plant behavior. His attack upon a new plant is governed by this generalized experience; he assumes a common biological response from his material, and his decision as to the procedure to follow in such a case is not determined haphazard, but by his knowledge and observation of that particular plant's normal habit of growth. As botany and horticulture become more closely allied it may be expected that the experienced propagator, recognizing the aim common to workers in both fields, with his wide and sympathetic understanding of the plant's behavior, will more and more help in the task of interpreting this behavior in terms of the still-rudimentary science which aims at expressing the facts as to the structure and physiology of the plant.

THEORIES OF POLARITY

All attempts to generalize as to the factors governing the production of new shoots and roots upon the plant seem to have been stimulated by a recognition of the innate polarity exhibited by the plant. The isolated shoot tends to produce adventive roots more readily than adventive shoots, and to produce them at the lower (proximal) end. The isolated root produces adventive buds more readily than adventive roots, and these buds appear most frequently at the upper (proximal) end. Thus, each portion of the plant acts as though it were trying to restore the old balance by the regeneration of the missing structure.

THEORY OF FORMATIVE SUBSTANCES

From the impression of this innate polarity exhibited by any isolated part of the plant, the conception developed that such an isolated system still contains two moving currents of formative substances, shoot-forming materials moving toward the shoot end, and root-forming materials moving toward the root pole. Largely through the writings of Sachs (*132*) this "formative-stuffs" hypothesis has had a wide popularity. A summary of this theory was given by Darwin (*28*) and another more recently by Hartsema (*56*). It is not proposed to give an account of its early development, as, apart from one special field of investigation, this standpoint is now only of historical interest.

In reference to this one problem, however—the effect of the condition of the plant at the time it is used for propagation upon the nature of the structures formed in regeneration—the phraseology of the "formative-stuffs" hypothesis is still usually employed, and in this field is found the only positive experimental evidence which has been brought forward in support of such hypothesis.

Effect of Maturity of the Plant Upon Its Regeneration

In his experiments with Begonia, Sachs (*133*) noted that adventive shoots grown from leaf cuttings taken from plants in flower themselves seemed to reach the flowering stage precociously early. These results were immediately expressed in the phraseology of the "formative-stuffs" hypothesis and were interpreted as due to the large amount of "flower-forming substances" which were naturally present in leaves isolated from plants at the flowering stage. Figdor (*36*) made similar observations with leaf cuttings of *Monophyllaea horsfieldii* R. Br., Wakker (*179*) with *Begonia rex*, Stewart (*151*) with stem cuttings of Gardenia; and indeed this particular characteristic of propagation has been repeatedly recorded in horticultural literature. Doposcheg-Uhlár (*30*) and Winkler (*185*) have pointed out that when leaf cuttings are taken from plants in which the leaf form changes with the maturity of the plant, the shoots from the juvenile forms take longer to reach the adult form of leaf than do adventive shoots arising on the adult-leaf form.

The phenomenon is not restricted to leaf cuttings. Stewart (*150*) recorded a striking experiment in which shoots were grown from a series of pieces taken from a single long root of Acanthus. The buds arising in the older pieces of the root produced the adult type of leaf very much earlier than did the buds from the youngest piece of root; this developed in succession a series of leaves passing from the juvenile to the adult form. Similarly in some species of Begonia and some Gesneriaceae, when the leaf cuttings are taken in the fall, swollen tuberous structures, closely covered with small modified leaves are produced instead of the usual vegetative buds.

Very few systematic attempts have been made to understand these propagation phenomena, though in at least one case an interesting experimental confirmation of the "formative-stuffs" hypothesis has apparently been supplied. Doposcheg-Uhlár (*30*) studied the development of tubers from leaf cuttings of "*Gesnera graciosa*"; a number of these tubers, which are freely formed in the fall, were collected, ground in sand in 50 per cent glycerin and left in the extracting medium for eight days. The extract was then filtered off, left in a desiccator for some months, during which a brownish yellow precipitate settled out. The following summer the glycerin extract was precipitated with alcohol, and the precipitate was washed with alcohol and finally dissolved in water and made a clear solution. Leaves of the Gesneria plants were then in some cases separated from the plant, the leafstalk being at the time of cutting immersed in this solution, while other leaves were injected with it. On the first occasion, at the end of July, when this was done, neither experimental leaves nor normally treated leaf cuttings developed anything but roots. In a later experiment, September 1, while the few normally treated leaves developed only leafy buds, the majority of the experimental leaves developed both buds and tubers, and in some cases tubers only. By November all the leaves of both checks and experimental plants had developed tubers.

These experiments are put forward by Doposcheg-Uhlár (*30*) as evidence that tuber formation is here to be regarded as caused by a "growth enzyme" of the general type suggested by Beijerinck (*11*) which accumulates in the leaves of these plants in the fall. The experimental method is assumed to extract this enzyme in the fall and to retain it so that it can be inoculated into the leaves the next summer and thus bring them to the point of tuber formation before they otherwise would reach it. However, the experimental evidence is not strong in support of this remarkable suggestion.

If such an enzyme were obtained by this method (which remains a pure hypothesis), then it should be most vigorous in the extract utilized in July; but no tubers were obtained at this time. By September, as is clear from the subsequent behavior of the normal plants, all leaves were approaching the period when tuber formation takes place, and it seems probable that the treatments adopted, i. e., immersing the leafstalk in the solution as it was severed, or injecting it subsequently with the solution, would have been equally effective in producing tubers if the solution had previously been boiled or indeed had been only water. The experimental treatment adopted would have left many tissues which take part in regeneration injected with liquid, and such treatment, quite apart from any question of enzyme activity, would have been sufficient to produce profound modifications in the behavior of the regenerating tissues. The check plants in this experiment are useless because they did not receive identical treatment with either boiled solution of the enzyme or pure water.

Doposcheg-Uhlár (*30*) himself showed in previous experiments that cuttings of *Achimenes longiflora* grown in water culture, might form either leafy aerial shoots or tubers below the level of the liquid, according to whether a culture solution, pure water, or tap water was employed. He also concluded that the different behavior in propagation shown by the juvenile, simple leaves of *Begonia carolineaefolia* Regel, as compared with that of the later formed compound leaves, was to be attributed mainly to the larger store of water and organic and mineral constituents present in the compound leaf.

FORMATIVE INFLUENCE OF QUALITATIVE OR QUANTITATIVE METABOLIC DIFFERENCES

The experimental basis for the hypothesis of " formative stuffs " in this type of experiment is, therefore, still quite inadequate. There is a growing tendency at the present time to associate flower formation, together with the frequently associated change in leaf form and in the general habit of the plant, with an altering balance of metabolism such as is expressed in the conception of the carbohydrate-nitrogen ratio. The experiments of Klebs (*74*) have thus led to the development of a new standpoint, especially in dealing with the flower formation, in which the process is related rather to quantitative seasonal differences in nutrition, than to qualitative differences in the nature of the substances reaching the growing point. Modern work in fruit culture especially is giving this new standpoint a very firm physiological foundation; however, the causal anatomy of the changes in the growing shoot apex which are involved constitutes a still-untouched field.

There are not wanting suggestions, moreover, that the new standpoint will prove equally valuable in relation to this similar problem in vegetative propagation. In fact, the junior writer (*158*) has already called attention to the striking similarity shown in the apple between the initiation of roots (burrknots) and the initiation of fruit buds. Goebel (*41*) in his general outlook on the problem of regeneration, emphasized the constitution and organization of the parent plant at the time of regeneration, rather than its content in particular formative substances.

Winkler (*185*) called attention to the fact that the practical gardener often prefers the method of propagation by seed to that by leaf, because the shoots from the leaf cuttings are apt to flower while still small and ineffective plants, whether the cuttings were taken from leaves at the time of flowering or earlier. He pointed out that the adventive shoots in the leaf naturally develop with a different metabolic balance at the outset, and that this difference may be greater in buds arising from leaves later in the summer. This changed metabolic balance may well be responsible for lessened growth and precocious flower production.

In the experiments of Dostal (*31, 32*) and of Němec (*98*), different formative powers in regeneration were shown by different parts of the shoot at the same time. Němec (*98*) found that while the basal region of the leaf of *Streptocarpus wendlandii* Spreng. produced adventive shoots giving only flower primordia, at the base of veins situated higher in the leaf adventive vegetative shoots appeared, while in between these two regions adventive structures often intermediate in character were obtained. To judge from its vigor in producing roots, the carbohydrate food supplies available were most plentiful at the base of the leaf, but this portion showed only a weak development of fertile adventive shoots. This is another indication that shoot production is not directly determined by the concentration of organic nutrients. The formative effect of the leaf upon the shoot organization produced in this plant could be obviated by removing the new shoot initials from the leaf at an early stage.

Dostal (*32*) similarly showed with *Circaea intermedia* Ehrh. that if pairs of leaves were isolated from the same plant, runners, flowering shoots, or transitional forms between these two structures were obtained according to their position on the plant. These experiments, however, clearly are better interpreted as the result of the effect of quantitative differences in the distribution of the same substances about the plant when it is severed for propagation, rather than as the result of the localized distribution of different formative substances. In particular, the latter hypothesis would need to be strained very far to justify a qualitative distribution of formative substances sufficient to explain the striking differences in regenerative power shown by a number of pieces of the same leaf, observed in some of Němec's experiments with Streptocarpus.

DIFFERENT "ANLAGEN" RATHER THAN DIFFERENT FOOD SUPPLIES

In the days when knowledge of the vascular channels and of food transport were so vague, special systems transporting different nutrient materials to shoot and root could easily be assumed. To take the origin of new apices within the pericycle of a young root as a concrete example, however, it is clear that these structures, appearing in the same position, draw upon the same vascular system and the same sources of supplies. This is true for all cases of shoots and roots. In the same plant all apices are dependent upon the same vascular system for the sources of materials used in their growth. The method of nutrition may be different, but the source of supplies is the same, and the differences between shoot and root can be no longer traced to an assumed difference in the formative qualities of the nutrient materials.

Another method of escaping the dilemma is evidenced by the readiness of many investigators of the present day to find refuge in the magic word "hormone." Growth in the plant quite probably is in part controlled by the diffusion, from one tissue to another, of chemical substances which affect permeability, protoplasmic powers of synthesis, and cell division, but it must be emphasized that at present the experimental basis for the assumption of any definite substances with specific chemical and biological properties is very meager and inadequate. Unless a hypothesis is both the basis and the result of an experimental examination which helps the elucidation of the problem of shoot and root formation, it becomes a stumbling block rather than an aid to understanding. The many facile generalizations as to growth-promoting and growth-inhibiting substances found in the literature to-day, too frequently constitute a refuge in words from any further attempt at understanding a difficult problem.

Loeb (*90*) began his interpretation of the phenomena of regeneration in Bryophyllum with the working hypothesis that the failure of the adventive or axillary shoot to grow out under certain conditions, might be due to the movement of growth-inhibiting substances into the neighborhood of these shoot organizations from the region of the growing dominant apical bud. But as he continued the quantitative analysis of the phenomena of regeneration, he became more and more impressed with the competitive character of the demands of the different growing organizations, whether shoot or root, upon the quantity of material available for growth. Implicitly, though nowhere very explicitly, Loeb abandoned the assumption of growth-inhibiting materials. On the new basis, the inhibition produced by one actively growing center upon the others is due to the fact that the materials available for growth are all moving to this already growing center and are there being utilized.

Loeb (*90*) found that the drain upon the available food supply was of the same effectiveness for equal amounts of new growth, whether the growth centers were shoot or root. This clearly indicates that such new structures utilize the same food reserves and not specifically different substances. But the phenomena of polarity remain to be explained, and Loeb concluded that in different regions of the plant this common supply of nutrients finds "anlagen" of different nature and therefore gives rise to different structures in the two regions. The explanation is thus shifted from the hypothesis of chemical differences in nutrient materials to an anatomical basis. With Loeb, however, this explanation remained completely hypothetical, for he made no attempt to identify these different "anlagen."

This anatomical basis for polarity can be critically examined in the light of the facts given in the preceding sections. It has been seen that there is no constant difference in the position of shoot and root "anlagen"; either may be exogenous, and either may be endogenous. Furthermore, in the detailed studies regarding the regeneration of shoot and roots in the neighborhood of the cut surface in Crambe, it becomes clear that given different conditions, a given group of cells might behave as cork phellogen, as the dermatogen of a new shoot apex, or as the outer layers of a root initial. Similarly, a given cell of the pericycle lying opposite a protoxylem group, clearly has the potentiality of forming part of a vascular cambium, a pericyclic phellogen, a root initial, or a shoot initial. As a rule, when once the meristem cells are organized into a characteristic "anlage" the organization does not change its character whatever the food supplied to it, though the exception to this rule is provided by the bud upon the root of *Rumex acetosella* which has been experimentally induced to grow on into a root apex (p. 26). Usually, if the food supplies permit of growth taking place, the organization of the meristematic apex determines the nature of the structure produced. The problem of polarity in regeneration then lies rather with the internal factors controlling the initiation of these "anlagen." Jones (*69*) has tried to utilize Child's theory of "axial gradients" (*24*) in interpreting the phenomena of polarity, but this theory has never grappled with a double axial gradient extending out from shoot pole and root pole at opposite ends of the growing organism, and, as Jones admits, such an assumption "adds little to an understanding of the causes underlying the facts."

ORGANIZATION AS THE BASIS OF DIRECTED MERISTEMATIC ACTIVITY

The anatomical and developmental study of regeneration has shown that any single meristematic cell is capable of forming part of an organized group which may function as any of the meristematic organizations characteristic of the plant, whether phellogen, cambium, or root or shoot apex. Possibly, like the germ cell, any single cell might be capable of giving rise to all such structures by continued cell division; but forming part, as it does from the beginning, of a cell organization, what the individual cell does is determined by its relative position in the organism. This is the main point that appears to emerge from this reexamination of the subject. The behavior of the living meristematic cell is determined by its position in a group and the behavior of the group by its relative position in a complex organization. Potentially any cell is capable of meristematic growth and may produce any cell organization characteristic of the species; practically, however, its possibilities are definitely limited by its position in a complex organization.

With the possible exception of some of the monocotyledons where the essential internal factors seem never to function, any living cell may return to the meristematic condition. Miehe (*96*) has recently suggested that the meristematic state is due to the presence in the cell of a hypothetical type of plasma, the archiplasm. No evidence is supplied for the existence of this special plasma and no effort made to seek it, so that this seems only another example of the too-common tendency to substitute words for working hypotheses (*83*). Miehe's suggestion seems completely incompatible with the striking observations made many years ago by Noll (*99*) upon *Bryopsis muscosa* Lamour.

In this coenocytic alga, Noll (*99*) found that the protoplasm and nuclei could be seen in the living filament, streaming from the side of the siphon where the protoplasm had been lying between central vacuole and wall, into the mass of protoplasm which filled the apex of the filament. As it slowly moved to this position, it always appeared to change in consistency, becoming more dense and less watery. Such a change in density was also suggested by the position of the chloroplasts, which he saw embedded in the protoplasm along the sides of the siphon, but which accumulated at the vacuole surface in the apex. At the apex, growth was proceeding, including presumably the manufacture of more protoplasm and the multiplication of nuclei. The protoplasm then streamed out of the apex again and down the siphon, so that the actual protoplasmic and nuclear content of the apex was always changing, but nevertheless growth activities remained centered there.

It seems impossible to think that in this case the behavior of the protoplasm is determined by the taking up of some hypothetical archiplasm as it enters the apex from the side of the siphon, and which is left behind again as the moving protoplasm leaves the apex. The phenomenon points rather to the behavior of the protoplasm being determined by its position in the siphon, and likewise the behavior of the meristem cell in the flowering plant is determined by its position in that more highly organized structure.

Relative position in a complex organism thus seems to determine whether each individual cell shall be meristematic and densely filled with protoplasm, semimeristematic, vacuolated and still dividing, or greatly extended with sap and showing no signs of growth activity. Hence the result of this anatomical study is to stress the significance of the position, not of preformed "anlagen" but of the living cells which by their coordinated activity give rise to shoot or root primordia. In the first section the different behavior of shoot and root apices was traced to differences in their organization. In the case of the adventive primordia so significant in propagation, their emergence is now seen to depend upon the response of the living cells of the plant to their new environment produced in the process of propagation when a portion of the completely organized plant is isolated and thus the relation of its living tissue systems to one another and to the external world is profoundly modified.

INFLUENCE OF ORGANIZATION UPON THE EMERGENCE OF THE ADVENTIVE MERISTEM

The problem of the initiation and maintenance of the meristematic condition in the cell, as a result of its position in a complex organization, already has been briefly considered. Two hypotheses have been advanced of recent years to interpret such phenomena. One, which invokes the operation of "wound hormones" as well as similar substances issuing from the phloem, does not seem at all applicable, in its present form, in accounting for the appearance of the meristematic condition except as the result of injury. The other hypothesis, that the hydrogen-ion concentration at the surface of the meristematic protoplast is an important condition of its characteristic activity, has recently been applied by the senior writer (*117*) to interpret the distribution of meristematic tissues in the plant that is intact as well as in the injured one.

There are sound a priori reasons for anticipating a significant effect of external pH upon a meristematic protoplast. The conditions found to exist in meristem cells in the higher plants suggest that the ratio of the total mass of the cell to its surface is a very important limiting factor determining size. This suggests that nutrients entering through the surface are utilized by all the mass of protoplasm and not merely by the nucleus. Under such conditions the external pH is likely to have a very direct influence upon the activity of the cell, because it profoundly influences the behavior of protein substances to water. This view is still a working hypothesis both requiring and permitting experimental examination; preliminary observations seem to point towards its general truth (*58*, *180*), but at the most it can be but one contributing factor.

The pH prevailing at the surface of the meristematic protoplast will also have a very great influence upon the permeability of the cell. It has been assumed that the protoplasmic surface is bathed in a medium which is near its isoelectric point; Michaelis (*95*) has shown that this would tend to make the protoplasm permeable both to anions and cations. Such an effect may have the greatest influence on the rapid entry of the solutes required for protoplasmic synthesis.

While a beginning has thus been made upon the problems of the initiation and maintenance of meristematic condition in general, the problem of the initiation of the one type rather than another seems to evade even formulation. At present it is difficult to indicate a possible experimental line of attack.

When the original apical meristems were under consideration, their differences in organization were connected with the difference in mode of nutrition, which seems to be determined by the chemical nature of their walls, and this in turn by the extent to which proteins and similar substances are withdrawn from the carbohydrate framework. It is very suggestive, therefore, to realize that the ease with which proteins and similar amphoteric substances separate from carbohydrate walls is a function of their relative electric charges and thus again very sensitive to the pH (*102*).

If, therefore, the meristematic condition were possible over but a limited range of pH around the isoelectric point of the protoplasmic proteins, at the relatively acid end of that range the proteins would only sluggishly clear from the cleavage plane on which carbohydrate was deposited, while at the relatively alkaline end of the range the proteins would leave the walls very promptly. Under these conditions the acid end of the range would favor the apical organization of the root, and alkaline conditions the shoot meristem. This is a very tentative suggestion indeed, but its consideration has been encouraged by the gradual development of the hypothesis of hydrogen-ion reaction in relation to the intercalary meristems.

The key to the difference between adventive shoot and root may quite probably be found in the oft-repeated ringing experiment, in which when the phloem is completely severed, buds subsequently appear below the ring and roots above. The buds are here found on the side of the root system and thus on the side which has by far the greater tendency toward positive sap pressures. Roots, on the other hand, are formed on the side where the downward movement (in the phloem?) brings materials to the ring.

Beijerinck's observations (*11*), referred to previously (p. 57), that bud production is more marked the nearer the cut surface is to the uninjured root system, together with the relatively ready production of buds upon the succulent type of leaf and upon fleshy roots, all accord with the apparent rôle of positive exudation pressures in the formation of shoot initials. Here, also, may lie the reason for the correlation, so clearly brought out by Beijerinck, between the position of the xylem and the adventive bud; in the radially organized root as well as in the dorsiventral leaf the adventive bud invariably appears in a superficial position opposite the xylem.

The opposed characteristics of phellogen and vascular cambium are very striking. The vascular cambium cuts off most cells to the inside, and these in their process of differentiation, lignification, and death, tend to maintain the acid reaction of the xylem sap. The phellogen cuts off most cells to the outside, which similarly tend to develop an acid reaction as they differentiate, suberize, and die. The cells formed towards the phloem by both meristems remain alive; they usually retain carbohydrate walls essentially free from other impregnating substances. It has been shown that there are reasons for regarding each of these meristems as lying across a gradient of hydrogen-ion concentration, but with the gradient running in opposite directions, the phloem which is outside one and inside the other, always supplies the alkaline end of the gradient. Now it is at least suggestive, since the pH can be indicated as possibly determining meristem organization as well as meristem activity, that in an axis bearing both these intercalary meristems, adventive shoot organizations are always formed in close association with the phellogen. The new root initial, on the other hand, is associated with the vascular cambium, the effective cells usually lying in a primary ray; these cells become more densely filled with protoplasm and more definitely meristematic than they were, but their walls are still impregnated with protein, and the most actively dividing layer is to the inside, abutting upon the cambium and the relatively acid supplies of the xylem.

Whether a group of meristem cells in the callus of seakale organize as a stem apex or a root apex, therefore, may depend in part upon the pH of the liquid bathing them. In this connection Riehm (*127*) found that when fragments of leaves of *Cardamine pratensis* were floated in a solution of KH_2PO_4 (relatively acid) they became meristematic and gave buds in three days and roots two days later, but when they were floated on K_2HPO_4 (relatively alkaline) roots were formed in three days and buds only after two weeks.

These suggestions can only be regarded as an indication of the type of problem that has emerged and requires solution. The main result of the present examination of the problems of vegetative propagation is the conclusion that success in this field depends upon the initiation and maintenance of meristematic tissues which are organized as adventive shoot and root apices. At least the clear recognition of the nature of the problem is the first step towards its solution, and the suggestion that the hydrogen-ion concentration in the neighborhood of the new meristem, a result of the organization of the living tissues around it, may play an effective part in the process, must at present simply be regarded as an illustration of the manner in which tissue organization in the isolated plant system may modify meristem growth and organization.

CONCLUSION

The detailed analysis of the anatomical basis of vegetative propagation presented in this bulletin does not readily admit of a summarized presentation, but the general conclusion that emerges can be concisely stated.

The problems of vegetative propagation among the flowering plants, viewed from the standpoint of causal anatomy, are the problems of the initiation and development of an adventive shoot or root, or both, upon an isolated portion of a living plant. The essential processes may or may not have started before severance from the parent plant.

Such adventive structures are not determined in their nature and position by the movement of special formative food substances in the plant, or by the existence of preformed "anlagen." Their production invariably involves the formation and maintenance of a meristematic tissue which is organized as either shoot or root apex. The internal and external conditions concerned with the initiation and maintenance of these meristematic groups of cells are examined. The conclusion is that "the behavior of the living meristematic cell is determined by its position" (p. 84) in the living tissue, and the manner in which position may influence subsequent growth and activity of the cell is explored in a preliminary manner, but in the main this must remain a problem for future investigation.

The subsequent development of such adventive apical meristems requires internal and external conditions essentially equivalent to those required for the development of the corresponding shoot or root apices upon the parent plants—conditions which are defined as closely as possible in the light of the writers' very meager information regarding the physiology of plant growth and differentiation.

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